PRINCETON
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®

INSTRUCTION MANUAL

LOCK-IN AMPLIFIER/PHASE DETECTOR

MODEL 121

PRINCETON APPLIED RESEARCH CORPORATION

PRINCETON, NEW JERSEY

INSTRUCTION MANUAL

LOCK-IN AMPLIFIER/PHASE DETECTOR

MODEL 121

THIS MANUAL APPLIES SPECIFICALLY TO MODEL 121 SERIAL NO. 529

Covered under one or more of the following U.S. Patents: #3,270,213, #3,296,463, #3,296,464.

NOTE: Material relating to changes, if any, will be found in envelope at rear of manual.

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SECTION I
CHARACTERISTICS

1.1 INTRODUCTION

The PAR™* Model 121 Lock-In Amplifier/Phase Detector is a dual purpose instrument. In addition to enabling the rms value of the fundamental frequency component of noisy signals to be measured quickly and accurately, it allows input signal phase variations to be measured independent of amplitude variations.

By selecting a band of frequencies from a signal spectrum and converting the information to an equivalent bandwidth about DC, the instrument is capable of operating with an extremely narrow equivalent noise bandwidth. The basic element of the Lock-In Amplifier is a phase-sensitive detector in which the signal to be measured is mixed with a reference signal at the same frequency, producing sum and difference frequencies. The difference frequency due to components of the signal at the reference frequency is zero (DC). A low-pass filter at the output of the mixer rejects the high frequency components corresponding to sum frequencies and passes the difference frequencies which lie within its passband. Difference frequencies differing from the reference frequency by more than the cut-off frequency of the low-pass filter are attenuated. Consequently, the output of the low-pass filter is due to that portion of the signal spectrum which lies about the reference frequency within a passband determined by the low-pass filter. By making the bandwidth of the filter narrow (increasing the time constant), the effect of input noise on the output signal can be greatly reduced, that is, the instrument can achieve a large improvement in signal-to-noise ratio.

For phase detection operation, limiting circuits remove all amplitude variations, thereby allowing phase variations in the input signal to be independently measured.

Featuring high sensitivity, low internal noise, and a wide range of operating frequencies, the PAR Model 121 Lock-In Amplifier/Phase Detector permits signal intensity and phase variation measurements to be made where noise would otherwise rule them out.

*PAR is a trademark of Princeton Applied Research Corporation.

1.2 LOCK-IN AMPLIFIER SPECIFICATIONS

GENERAL

(1) FREQUENCY RANGE

Tunable from 1.5 Hz to 150 kHz in five ranges.

(2) FREQUENCY SETTING ACCURACY

±5%.

(3) INTERNAL NOISE

At 1 kHz, the noise figure shall be less than 3 dB for resistive sources between 50 kΩ and 5 MΩ.

(4) FILTER TIME CONSTANTS

1 millisecond to 100 seconds in 1, 3, 10 sequence. Any particular time constant desired may be obtained by the use of external capacitors. 6 dB/octave or 12 dB/octave roll-off is available.

(5) OUTPUT STABILITY

Stable to within 0.1% of full scale output per 24 hours (constant ambient temperature).

(6) GAIN STABILITY

±0.5% at 400 Hz (Q of 10).

(7) LINEARITY

±0.1% of full scale.

(8) POWER REQUIREMENTS

105-125 V or 210-250 V; 50-60 Hz; 18 watts.

SIGNAL CHANNEL

(1) SENSITIVITY

10 microvolts to 500 millivolts for full scale output in 1, 2, 5 sequence. Provision for increasing meter sensitivity by a factor of ten on any range.

(2) INPUT RESISTANCE

Single-ended input of 10 MΩ shunted by 30 pF.

(3) SELECTIVITY

Adjustable Q from 5 to 25 over the entire frequency range.

(4) ZERO SUPPRESS

Calibrated suppress from zero to ±1000% of full scale. Suppress Polarity Switch has off position for removing suppress signal, if desired.

(5) OUTPUTS

(a) Panel Meter. The scales on the meter correspond to the Sensitivity Switch positions.

(b) Front panel BNC Monitor Jack. ±10 V through 4.7 kΩ.

(c) Rear panel binding posts. Recorder output suitable for driving most galvanometric or servo type recorders. The output impedance is variable from 7 to 22 kilohms. Consequently, full scale output (±10 V) will give ± full scale deflection with either 0.5 mA-0-0.5 mA or 1.0 mA-0-1.0 mA recorders.

REFERENCE CHANNEL

(1) INPUT/OUTPUT RESISTANCE

A function of the Reference Mode as follows.

MODE	INPUT RESISTANCE	OUTPUT RESISTANCE
CAL. 10 mV		50Ω
INT.		600Ω
SEL. EXT.	10 kΩ	
EXT. f/2	2 MΩ	
EXT.	10 kΩ	

(2) PHASE SHIFTER

A calibrated ten-turn phase-shift dial with a range of 0° to 100° allows phase shifting of the reference signal in all but the "EXT." Mode of operation. A Phase Quadrant Switch allows additional incremental phase shifts of 90°, 180°, or 270°.

(3) MODES OF OPERATION

(a) SELECTIVE EXTERNAL

Externally generated reference signal filtered by tuned amplifier with a Q of 10. Minimum of 50 mV rms required.

(b) EXTERNAL

Requires externally generated signal of 1 V ptp minimum. Signal must cross its mean value only twice each cycle with equal time between crossings. Phase shifting to be done externally.

(c) EXTERNAL f/2

Second harmonic of external reference signal is internally generated and applied to the tuned amplifier. Input signal must be a sine or triangular wave within the range of 1.5 V to 5.0 V rms. Phase Control effective.

(d) INTERNAL

Internal oscillator drives the demodulator and provides a signal (continuously variable over the range of 0 to 1 V rms) at the tuned frequency to the front panel "REF. IN/OUT" Jack. The output impedance is 600Ω.

(e) CALIBRATE

A 22.2 mV ptp square wave (rms value of the fundamental frequency component is 10 mV ±1%) at the tuned frequency is provided at the "REF. IN/OUT" Jack. The output impedance is 50Ω.

1.3 PHASE DETECTOR SPECIFICATIONS

GENERAL

With the exception of the linearity specification, which changes from ±0.1% to ±0.5% of full scale, the general specifications for the Phase Detector are the same as for the Lock-In Amplifier (1.2).

SIGNAL CHANNEL

(1) SIGNAL LEVEL REQUIRED

Generally as indicated by the Sensitivity Switch setting.

(2) SENSITIVITY

±90° phase shift yields ±90% of full scale output (maximum possible output for Phase Detector operation). This specification applies to noiseless signals only.

(3) ZERO SUPPRESS

Because the signal output of the Phase Detector is independent of input signal amplitude, the Zero Suppress Control serves only to shift the output "reference level".

(4) PHASE MEASUREMENT ACCURACY

(a) From 5 Hz to 50 kHz, the accuracy is ±10°.

(b) From 50 kHz to 150 kHz, the accuracy is ±15°.

(c) The instrument cannot be used for phase measurements below 5 Hz.

REFERENCE CHANNEL

The Reference Channel Specifications are exactly the same as for Lock-In operation.

SECTION II
INITIAL CHECKS

2.1 INTRODUCTION

The following procedure is provided to facilitate initial performance checking of the Model 121 Lock-In Amplifier/Phase Detector. In general, this procedure should be carried out after inspecting the instrument for damage (any noted to be reported to the carrier and to PAR), but before using it experimentally. This procedure presupposes no knowledge of the Model 121 on the part of the checker. Should any difficulty be encountered in carrying out these checks, contact the factory or one of PAR's authorized representatives, a list of whom appears at the end of the manual.

2.2 EQUIPMENT NEEDED

(1) General purpose oscilloscope such as the TEKTRONIX type 545 with a type CA plug-in.

(2) Sine wave oscillator, capable of generating 6 V ptp at 380 Hz into 10 kΩ.

(3) Coaxial cable, approximately six inches long, with a BNC connector at each end.

(4) Cable, suitable for coupling the oscillator output to the Model 121 "REF. IN/OUT" Jack.

2.3 PRELIMINARY STEPS

(1) Plug in the line cord and turn the power on.

(2) Allow a five-minute warm-up period.

2.4 CHECK-OUT PROCEDURE USING INTERNAL CALIBRATOR

(1) Set the front panel controls as follows.

Sensitivity -------------------------	20 mV
Signal Q ----------------------------	10
Frequency Multiplier ----------------	10^2
Frequency Dial ----------------------	3.8
Phase Control -----------------------	0
Phase Quadrant Switch ---------------	0
Time Constant -----------------------	300 ms; 6 dB/octave
Mode --------------------------------	CAL. 10 mV
Meter/Monitor Switch ----------------	SIG.
Zero Suppress Toggle Switch ---------	Center position
Zero Suppress Control ---------------	fully counter-clockwise
Reference Attenuator Switch ---------	1
Reference Attenuator Vernier --------	fully clockwise

(2) Using the six inch coaxial cable, connect the "REF. IN/OUT" Jack to the "SIG. IN" Jack.

(3) Adjust the "FREQ. TRIM" Control for maximum meter indication (about 50% of full scale to the right).

(4) Set the Sensitivity Switch to 10 mV.

(5) Turn the "ADJ." Control with a screwdriver to obtain full scale meter indication.

(6) Set the Meter/Monitor Switch to each of the following positions, noting that the indicated panel meter deflection is obtained for each position.

Meter/Monitor Position	Meter Indication
PHASE --------------------------------	between +78% and +92% full scale.
REF. ---------------------------------	between +43% and +57% of full scale.
OFF ----------------------------------	0
OUT ----------------------------------	between +95% and +105% of full scale.

(7) Turn the Zero Suppress Control exactly one full turn clockwise (the Meter/Monitor Switch should still be set to "OUT"). Then set the Zero Suppress Toggle Switch to "+". The panel meter will now indicate 0, ±5% of full scale. Set the Zero Suppress Toggle Switch to its center position. The meter will return to its original indication.

(8) Set the Quadrature Switch to "180°". The panel meter should indicate between -95% and -105% of full scale.

(9) Set the Sensitivity Switch to 100 mV. The panel meter indication should decrease to approximately -10% of full scale.

(10) Set the Meter/Monitor Switch to "OUT X10". The meter indication should indicate between -85% and -110% of full scale.

(11) Set the Meter Monitor Switch to "OUT" and the Sensitivity Switch to 10 mV.

(12) Check that the Phase Dial setting determines the panel meter indication as follows.

Phase Dial	Meter Indication
60° ----------------------------------	between -30% and -70% of full scale.
90° ----------------------------------	0, ±20% of full scale.

(13) Remove the cable interconnecting the "REF. IN/OUT" Jack and the "SIG. IN" Jack.

(14) After setting the Mode Switch to "INT.", monitor the "REF. IN/OUT" Jack with the oscilloscope. A 2.8 V (±400 mV) ptp sine wave at 380 Hz should be observed.

2.5 CHECK-OUT PROCEDURE USING EXTERNAL SOURCE

(1) Set the Model 121 controls as follows.

Reference Attenuator ----------------------	0.05
Reference Attenuator Vernier -------------	center of range
Mode --------------------------------------	SEL. EXT.
Meter/Monitor Switch ---------------------	REF.

(2) Apply a 6 V ptp, 380 Hz sine wave (using the external oscillator) to the "REF. IN/OUT" Jack.

(3) Carefully adjust the large Frequency Control to obtain maximum meter indication. At maximum, the meter indication should be between 40% and 100% of full scale.

(4) Set the Mode Switch to "f/2". Adjust the large Frequency Control for maximum meter indication. Peak meter indication should correspond to a Frequency Control setting of approximately "7.6".

(5) After setting the Mode Switch to "EXT." and the Reference Attenuator Switch to "0.5", turn the Reference Attenuator Vernier fully clockwise. The panel meter should indicate approximately +50% of full scale.

THIS COMPLETES THE INITIAL CHECKS. IF THE MODEL 121 PERFORMED AS INDICATED, ONE CAN BE REASONABLY SURE THAT THE INSTRUMENT IS OPERATING PROPERLY.

SECTION III
OPERATING INSTRUCTIONS

3.1 INTRODUCTION

Beginning with some preliminary considerations such as power requirements and cooling, this section of the manual covers the procedures to be followed in obtaining maximum performance from the Model 121. Because operation of the instrument as a Phase Detector differs from operation as a Lock-In Amplifier, the two subjects are treated separately. Among the topics covered are gain and phase calibration, choice of reference mode and Q, overload considerations, and use of a strip-chart recorder.

Although the primary purpose of the Model 121 is to function as a Lock-in Amplifier or Phase Detector, it has a third capability, that of operating as a simple tuned voltmeter of variable sensitivity and bandwidth. This capability is discussed towards the end of the section.

3.2 PRELIMINARY CONSIDERATIONS

INSTALLATION

The Model 121 can be either bench or rack mounted, and if rack mounted, can be equipped with "slides" to facilitate moving the instrument in and out of the rack. Suitable slides can be purchased from:

JONATHAN MANUFACTURING COMPANY
1258 TEANECK ROAD
TEANECK, NEW JERSEY

To slide-mount the Model 121, the following parts, or their equivalents, will be required.

QUANTITY	ITEM
1 pair	STEEL BALL BEARING SLIDE, QUICK DISCONNECT, PART NUMBER 110 QD-14-1 or 110 QD-16-1 (the "14" and "16" refer to the length of the slide in inches).
4	MOUNTING BRACKET, PART NUMBER SP-0440

The instrument is supplied with the slide mounting holes already drilled in the sides. To gain access to these holes and mount the slides, remove the side covers, which slide off once the top and bottom covers are removed. The top cover slides free after removal of the two screws located under the top cover "lip" at the rear of the instrument. The bottom cover slides free after removal of the two rear bumper feet, each of which is held in place by a single screw. To mount the slides, use 7/32", 10-32, nickel-plated steel, round-head or pan-head screws.

POWER REQUIREMENTS

The Model 121 operates from either 105-125 or 210-250 V AC, 50-60 Hz,

and requires about 18 volt-amperes of power. Changeover from one operating voltage to the other is accomplished by actuating the Line Voltage Selector Switch, which is mounted on the bottom surface of the chassis. For operation from 105-125 V AC, "115" should show in the switch window. For operation from 210-250 V AC, "230" should show.

To gain access to the switch, one must first remove the bottom cover, which slides off after removal of the rear bumper feet.

FUSING

A slo-blo ¼ ampere fuse located at the rear panel is in series with the primary winding of the power transformer. Two additional 3/8 ampere fast-blo fuses, located internally, protect the +24 and -24 V regulators.

WARM-UP PERIOD

For most applications, five minutes. If exacting requirements necessitate that the instrument fully meet the Gain and Output Stability specifications, allow half an hour.

TEMPERATURE RANGE

The instrument can be operated over an ambient temperature range of 15° to 45°C.

3.3 OPERATION AS A LOCK-IN AMPLIFIER

Making a measurement when using the instrument as a Lock-In Amplifier can be broken down into a definite sequence of steps as follows.

(1) Calibrate the gain at the operating frequency (3.5).

(2) Determine the reference mode appropriate to the experiment, connect the reference signal, and optimize the setting of each reference channel control (3.6).

(3) Connect the signal to be measured and optimize the setting of each signal channel control (3.7).

(4) Take the reading (3.7). If desired, connect a recorder (3.8).

In the following pages, each of these steps is discussed in some detail, as are several related topics, among them the three types of overload and working at low signal levels. Careful study will insure optimum instrument performance under given experimental conditions. Figure III-1, a photograph of the instrument, is provided as a reference.

3.4 METER/MONITOR SWITCH

As each of the above steps involves setting the Meter/Monitor Switch to a different position, some explanation of the function of the switch as it pertains to Lock-In operation is warranted. "Lock-In" measurements are made

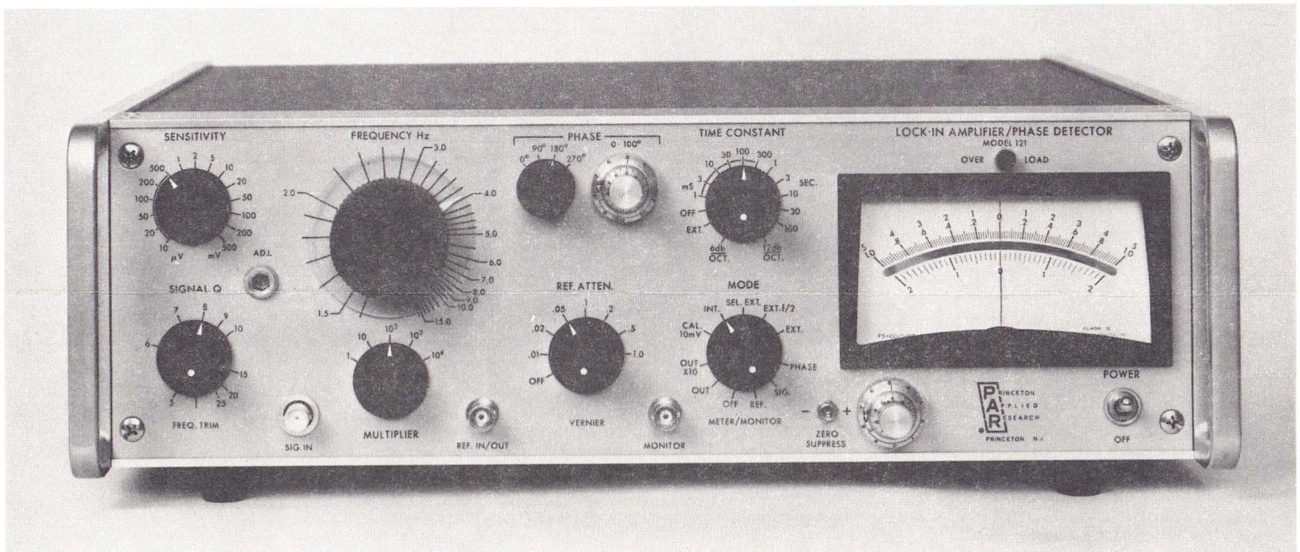


Figure III-1. MODEL 121 LOCK-IN AMPLIFIER

with the switch set to either "OUT" or "OUT X10", in which positions the panel meter indicates the rms value of the fundamental frequency component of the input signal. Before a measurement can be made, however, it is first necessary to optimize the setting of each control, some of which are adjusted with the switch set to "REF." and others with it set to "SIG."

When the Meter/Monitor Switch is set to "REF.", the meter indicates the amplitude of the reference signal. For the two reference modes in which the reference signal is applied to a tuned amplifier, "SEL. EXT" and "EXT. f/2", the meter simultaneously indicates proper tuning. In these two modes, by tuning for maximum deflection and then setting the Reference Attenuator Controls for optimum meter indication (50% of full scale), one is assured not only that the reference is of proper amplitude, but also that the Model 121 Reference Channel is tuned exactly to it. Although the meter indicates no tuning information in the other reference modes, it is still useful in setting the proper reference signal amplitude.

When the Meter/Monitor Switch is set to "SIG." the meter indication is maximum when the Signal Channel is tuned to the signal frequency. Because the Fine Frequency Control affects the Signal Channel only (the main frequency controls affect both channels), the Fine Frequency Control can be used in "SIG." to fine tune the Signal Channel prior to making a measurement. In this way, one is assured that both channels are tuned to the input frequency. It should be pointed out that with the Meter/Monitor Switch set to "SIG.", the instrument becomes an average responding, rms calibrated, tuned AC voltmeter. The meter directly indicates the level of the input signal over the bandwidth determined by the Q setting. Use of the instrument in this manner is treated in detail under "AC VOLTMETER OPERATION", page III-23. Setting the Meter/Monitor Switch to "PHASE" transfers the instrument to phase detector operation.

3.5 GAIN CALIBRATION

Prerequisite to calibrating the gain are: (1) tuning the Model 121 to the frequency of the signal to be measured, and (2) selecting the operating value of Q. Two controls determine the tuned frequency, the first being the upper tuning dial, continuously variable from "1.5" to "15", and the other being the decade multiplier, with a range of "X1" to "X10^4". The tuned frequency is simply the product of the two control settings. For example, if one intends to operate at 400 Hz, the upper dial should be set to "4.0", and the lower to "X10^2". Because the gain of the instrument is not completely independent of Q, it is necessary to select Q prior to making the gain calibration. Those factors which determine the choice of Q setting are discussed in detail under "Q CONTROL", page III-10. However, it may suffice here to say that a Q of ten is satisfactory for most Lock-In Amplifier applications.

Perhaps a word or two concerning the choice of operating frequency is in order. Operation is easiest and least subject to error and problems over a frequency range having as its lower limit a few hundred Hz, and as its upper, perhaps 10 kHz. NOTE: The instrument <u>does</u> meet specifications over its entire operating range. At very low frequencies, instrument response time increases measurement problems, while at very high frequencies, radiation and

associated pick-up tend to become bothersome. A special case is 60 Hz and its third harmonic, 180 Hz (50 Hz and 150 Hz where the power frequency is 50 Hz). Although instrument performance is in no way degraded by operating at the line frequency, the experimenter increases (perhaps unnecessarily) the problem of assuring that the signal supplied to the Lock-In originates from the experiment only, and not from stray pickup, either internal or external.

The following procedure calibrates the 10 mV sensitivity range to within one percent. Once calibrated, the other sensitivity ranges will be accurate to within two percent if the operating frequency is below 15 kHz, and to within five percent if the operating frequency is 15 kHz or higher. One percent accurate gain calibration (at any frequency) of any of the more sensitive ranges (10 microvolts through 5 millivolts) is possible by attenuating the 10 mV calibration signal (available at the "REF. IN/OUT" Jack at an impedance of 50 ohms) with precision external attenuators. The gain calibration procedure follows.

(1) Set the front panel controls as follows.

Mode Switch ---------------------------	CAL. 10 mV
Meter/Monitor Switch ----------------	SIG.
Sensitivity Switch ------------------	10 mV
Time Constant -----------------------	100 ms
Zero Suppress -----------------------	Toggle Switch to center position
Phase Quadrant Switch --------------	270°
Phase Dial --------------------------	90°

(2) Frequency Trim Adjustment

(a) Connect a coaxial cable from the "REF. IN/OUT" Jack to the "SIG. IN" Jack.

(b) Adjust "FREQ. TRIM" for peak panel meter indication.

(c) If the meter indication exceeds full scale, turn the screwdriver adjustable "ADJ." Control CCW as necessary to obtain an on-scale indication.

(3) Calibration

(a) Set the Meter/Monitor Switch to "OUT".

(b) Vary the Phase Dial for maximum positive meter indication. The final setting will be within a few degrees of 90° (actually 0°, 270° + 90° = 360° or 0°).

(c) Set the "ADJ." Control for exactly full scale meter indication, completing the calibration.

(d) Remove the cable.

3.6 REFERENCE CHANNEL OPERATION

After the gain has been calibrated at the operating frequency, the next step is to select the reference mode appropriate to the experimental conditions and to establish proper reference channel operation. As the requirements and operating procedure for each mode are different, each is treated separately.

SELECTIVE EXTERNAL

The Selective External Mode is the "normal" reference mode, that is, it is that mode which, because of the combined features of high sensitivity and full phase control, allows the use of the widest possible variety of reference signals in synchronizing the Model 121 with the signal to be measured. Reference signals which have a fundamental frequency component as low as 50 mV can be used in this mode. Sinusoidal, square, triangular, and sawtooth waves are all suitable, providing they are of sufficient amplitude and synchronous with the signal to be measured. Exact symmetry is not essential. The following procedure will check the suitability of the input signal, establish its amplitude at the proper level, and tune the Reference Channel to the input frequency.

(1) Set the controls as follows.

Mode -------------------------------- SEL. EXT.
Meter/Monitor Switch ---------------- REF.

(2) Connect the reference signal to the "REF. IN/OUT" Jack.

(3) Adjust the Reference Attenuator Controls for a meter indication of approximately 50% of full scale.

(4) Adjust the main frequency dial to maximize the meter indication.

(5) Adjust the Reference Attenuator for exactly 50% of full scale indication.

(6) With the control setting combination of "SEL. EXT." and "REF.", the output of the Reference Tuned Amplifier is provided at the front panel Monitor Jack at an impedance of 4.7 k. Providing the reference signal is of sufficient amplitude and at the tuned frequency, the signal at the Monitor Jack will be at least a "reasonable approximation" of a sine wave. This signal is at a +10 V DC level, and, assuming the meter indication is 50%, will have a peak-to-peak amplitude of about 2.8 V.

EXTERNAL

This reference mode is suitable when there is available a reference signal of sufficient amplitude (minimum of 1 V peak-to-peak) and proper waveform, and which is either inherently in phase with the signal (Model 121 phase controls are not effective in this mode) or which can be phased by an adjustment in either of the sources supplying the signal or reference inputs.

Sine waves and symmetrical square and triangular waves are suitable reference waveforms. In general, any waveform can be used if the zero crossings are equally spaced, if there are only two zero crossings in each cycle, and if the voltage rises sharply at each crossing.

The suitability of the reference signal may be verified with the following procedure.

(1) Set the controls as follows.

Mode Switch -------------------------	EXT.
Meter/Monitor Switch ----------------	REF.
Reference Attenuator ----------------	1.0
Reference Vernier -------------------	fully clockwise

(2) Connect the reference signal to the "REF. IN/OUT" Jack.

(3) Observe the meter. If the indication is greater than 50%, adjust the Reference Attenuator and Vernier to obtain a 50% of full scale indication. If the indication is less than 50% even though the reference input waveform satisfies the above criteria, do not disturb the setting of these controls.

(4) For convenience in examining the waveform, the reference signal is available at the Monitor Jack at an impedance of 4.7 k. Its amplitude, relative to the amplitude of the signal applied to the "REF. IN/OUT" Jack, is determined by the setting of the Reference Attenuator and Vernier Controls, and it is referenced to ground.

EXTERNAL f/2

In this mode the frequency of the reference signal is doubled, permitting the study of second harmonic signals. The reference input signal must be a sine wave or a triangular wave within the range of 1.5 to 5 V rms and must be at one-half the frequency to which the Model 121 is tuned. As the Phase Controls are effective in this mode, the external phasing requirement of the External Mode does not apply to the External f/2 Mode. The following procedure will check the suitability of the input signal and will tune the Reference Tuned Amplifier to the tuned frequency.

(1) Set the controls as follows.

Mode --------------------------------	EXT. f/2
Meter/Monitor Switch ----------------	REF.

(2) Connect the reference source to the Reference In/Out Jack.

(3) Adjust the Reference Attenuator/Vernier for a meter indication of approximately 50%.

(4) Adjust the tuning dial for maximum meter indication.

(5) Adjust the Reference Attenuator/Vernier for exactly 50% of full scale meter indication.

(6) The output of the Reference Tuned Amplifier is available at the Monitor Jack. The signal should be a "reasonable" sine wave at the tuned frequency and at a DC level of +10 V. Providing the meter indication is proper (50% of full-scale), the signal amplitude will be approximately 2.8 volts peak-to-peak.

INTERNAL

The Internal Reference Mode of operation is applicable when the experimental signal source does not itself generate a suitable reference signal, but is capable of being synchronized by a signal developed in the Model 121. When the Mode Switch is set to "INT.", a suitable synchronizing signal is available at the Reference In/Out Jack at an impedance of 600 ohms. This signal is a sine wave, referenced to ground. Its amplitude depends on the setting of the Reference Attenuator/Vernier. When set for maximum output, the amplitude is approximately 2.8 V peak-to-peak (one volt rms). If the Meter/Monitor Switch is simultaneously set to "REF.", a similar 2.8 V peak-to-peak signal (DC level approximately +10 V in this case) will be available at the Monitor Jack. The amplitude of this signal is independent of the setting of the Reference Attenuator/Vernier.

When the Meter/Monitor Switch is set to "REF.", proper operation of the instrument in the Internal Mode is indicated by a panel meter indication between 43% and 57% of full scale.

CALIBRATE

In the Calibrate Mode, a 10 mV ±1% (amplitude of fundamental component) calibration signal is provided at the Reference In/Out Jack for calibrating the Model 121 gain (page III-3). This signal is a symmetrical square wave at the tuned frequency with a peak-to-peak amplitude of 22.2 mV. The fundamental-frequency Fourier component of such a square wave can be shown to be 10 mV rms. The baseline voltage is approximately +20 mV.

By setting the Meter/Monitor Switch to "REF." during calibrate operation, one obtains the same Monitor Jack signal and panel meter indication as for Internal Mode operation.

3.7 SIGNAL CHANNEL OPERATION

Assume that the gain has been calibrated and proper operation of the Reference Channel established. It remains to fine tune the Signal Channel, connect the signal to be measured, optimize the setting of the Phase and Time Constant Controls, and take the reading. It might be mentioned that the Q Control should have been adjusted prior to the gain calibration. If the Q is changed, the gain may be affected. Whether or not the gain change will be sufficient to warrant recalibration depends largely on the operating frequency. At low and midrange frequencies, the change in gain resulting from changes in Q is small and in many applications may be considered negligible.

When the Frequency Multiplier is set to "X10^4", however, the change in gain is sufficiently large to require recalibration after a change in Q.

The following procedure is suitable for properly adjusting the Signal Channel Controls.

(1) Supply the reference signal simultaneously to the Reference and Signal Inputs. It may be necessary to attenuate that portion of the reference signal being supplied to the Signal Input.

(2) Set the Meter/Monitor Switch to "SIG."

(3) Set the Sensitivity Switch as required to obtain an up-scale indication.

(4) Adjust the Fine Frequency Control for maximum meter indication, thereby tuning the Signal Channel to exactly the same frequency as the Reference Channel. With a high Q setting, this adjustment becomes critical at the high end of the Frequency Dial on all frequency ranges.

NOTE: If the operator is using the "EXT." Reference Mode, first set the Main Tuning Dials for maximum meter indication. The dial setting at maximum meter indication should be within a few percent of the reference frequency. In all other reference modes, the Main Tuning Dials are adjusted earlier (Meter/Monitor Switch set to "REF.") and so should not be disturbed.

(5) Disconnect the reference signal from the Signal Input.

(6) Set the Meter/Monitor Switch to "OUT".

(7) Connect the signal to be measured to the Signal Input.

(8) Set the Sensitivity Switch to that position which results in the highest on scale meter indication (left or right). If the initial phase setting is "off" by approximately 90°, the instrument will reject the input signal. Consequently, if the Sensitivity Switch must be set to a far more sensitive setting than what the known strength of the signal indicates, rotate the Phase Dial through its range of adjustment to find the setting which yields maximum meter indication (left or right). It may be necessary to advance the Phase Quadrant Selector one step to achieve the maximum. Increase the time constant as necessary to achieve a steady indication.

(9) Carefully adjust the Phase Dial as necessary to maximize the meter indication. In adjusting the Phase Dial for maximum indication, the two inputs are brought either in-phase (positive maximum) or 180° out-of-phase (negative maximum). Although negative and positive readings are equivalent, it may be more "aesthetic" to always obtain a positive reading. If the obtained maximum is negative, rotate the Phase Quadrant Switch two steps, thereby phase-shifting the reference signal 180° to reverse the polarity of the output. A convenient check for determining that the Phase Dial is properly set is to

rotate the Phase Quadrant Switch one step, that is, shift the reference 90°. As signals in quadrature yield no output, the meter indication should go to zero. In other words, when the Phase Control is adjusted such that shifting the Phase Quadrant Switch one step clockwise or counter-clockwise causes the meter indication to go to zero, the Phase Control is properly adjusted.

(10) Note the meter indication. It now directly indicates the rms amplitude of the fundamental component of the input signal. Full scale meter indication corresponds to the selected sensitivity.

A factor to consider if one intends to operate on the most sensitive ranges is internal pickup. To check for this effect, set the Sensitivity Switch to "10 µV" and observe the panel meter (Meter/Monitor Switch to "OUT"). The Signal Input Jack should be shorted with an ordinary BNC shorting cap. If any indication is noted, set the Zero Suppress to "+" or "-", whichever is appropriate, and adjust the Zero Suppress Dial for a meter indication of "0". Repeating the adjustment with the Meter/Monitor Switch set to "OUT X10" may be advisable if the operator anticipates a small output. After suppressing any pickup, reconnect the input signal and return the Sensitivity Switch to its original setting to take the measurement.

A DC voltage proportional to the meter indication (full scale equals 10 V) is simultaneously available at the Monitor Jack through a 4.7 kilohm resistance and at the rear-panel Recorder Output at a resistance which can be varied from 7 kilohms to 22 kilohms with the associated Recorder Adjust Control.

Alternatively, the procedure could be modified as required to adjust the Fine Frequency Control using the experimental signal instead of the reference signal. This adjustment can be made with the Meter/Monitor Switch set to either "SIG." or "OUT". To make the adjustment with the Meter/Monitor Switch set to "SIG.", simply connect the signal, select the appropriate sensitivity, and adjust the Frequency Trim Control for maximum meter indication. Making the adjustment with the Meter/Monitor Switch set to "OUT" differs in that the Phase Control cannot be ignored. Both the Phase Control and the Frequency Trim Control should be adjusted for maximum meter indication. Also, the reference signal must be connected and the reference channel operating properly.

In any case, whether the Fine Frequency Control is to be adjusted using the experimental signal or a portion of the reference signal depends on the noise content of the experimental signal. If the signal is very noisy, the long time constant required makes adjusting the Fine Frequency Control with the experimental signal both difficult and tedious. If this signal is relatively noise free, adjusting the control using the experimental signal is easier and faster than using the reference signal. In conclusion, with noisy input signals ("normal" for lock-in measurements), follow the procedure exactly as given. With quiet input signals, either follow the procedure as given or modify it as required to set the Fine Frequency Control using the experimental signal as the input instead of the reference signal.

TIME CONSTANT

Noise accompanying the signal and appearing at the output can be reduced by increasing the time constant, the limit being when the time constant is so large as to cause significant variations in signal intensity to be "missed". In general, the time constant is set by observing the panel meter and increasing the time constant until a satisfactory compromise between suppression of noise and speed of response is reached. The time constant in the "OFF" position is approximately 100 microseconds and the roll-off is approximately 12 dB per octave.

Note that the operator has a choice of either a 6 dB per octave or a 12 dB per octave roll-off. Among the factors to be considered in choosing the roll-off rate are output rise time, equivalent noise bandwidth, and, where applicable, servo-loop stability. With a 6 dB/octave roll-off, the equivalent noise bandwidth is 1/4 RC and the rise time (10% to 90%) is 2.2 RC. With a 12 dB/octave roll-off, these figures become 1/8 RC and 3.4 RC. Clearly, for the same RC produce, 12 dB per octave gives better noise suppression at the expense of slightly slowed response. If the instrument is to be used as part of a servo system, loop stability criteria may dictate the use of the 6 dB per octave rate.

If the operator desires a time constant greater than 100 seconds, or a particular time constant other than those provided, he can set the Time Constant Switch to "EXT." and obtain the desired time constant by connecting capacitors of appropriate value to the rear-panel eleven-pin socket. To obtain a 6 dB/octave roll-off, two capacitors, designated C_1 and C_2, are required. For 12 dB/octave three capacitors are required (C_1, C_2, and C_3). C_1 and C_2 should be T/4 microfarads, where T is the time constant in seconds, and C_3 should be T/8 microfarads. Capacitor C_1 is to be connected between pins 2 and 7, C_2 between pins 3 and 6, and C_3 between pins 4 and 5. Capacitor C_3 has no effect unless the switch is set to 12 dB/octave. Only non-electrolytic capacitors should be used. Mylar, polystyrene, and polycarbonate film types rated at 50 volts or higher are preferred.

Q CONTROL

Initial noise rejection in the Model 121 is accomplished by the Signal Tuned Amplifier. The bandwidth of this amplifier, and hence the noise rejection, is directly determined by Q, the 3 dB bandwidth in Hz being the dialed frequency divided by the set Q. Because the noise passed by the amplifier varies with the square root of the bandwidth, best noise performance is obtained with a high Q. However, as the overall noise bandwidth of the instrument is usually determined mainly by the time constant, this improvement is very small. The main advantage of high Q operation is that it allows high amplitude interfering signals at frequencies near the tuned frequency to be rejected, thereby preventing them from overloading the Mixer. Because there are distinct disadvantages to operating with a high Q, unless one is concerned with high level interfering signals near the tuned frequency, or with extremely noisy signals, it will usually be better to operate at the "normal" Q of ten. Among the problems associated with high Q operation are: (1) properly setting the Frequency Trim Control becomes difficult, (2) the gain stability is degraded, (3) the characteristic time constant is more bothersome

at low frequencies, and (4) significant phase errors result from small frequency drifts.

Operation at the lowest Q setting (five) may be advantageous where it is important to achieve maximum gain stability, such as when one is recording small variations in signal intensity over an extended period of time. Another application which might necessitate use of a Q of five is low frequency operation. By using the smallest Q, the characteristic time constant ($Q/\pi f$ seconds, where f is the tuned frequency) will be as small as possible and the instrument will recover as quickly as possible from transients (see "LOW FREQUENCY OPERATION", which follows). In general, however, a Q of 10 will prove satisfactory in most applications.

3.8 LOW FREQUENCY OPERATION (1.5 Hz to 15 Hz)

When the Model 121 is operating at a frequency in the range of 1.5 to 15 Hz, the time required to reach steady state after any change in signal level or frequency is long enough to be perceptible. The behavior of the tuned amplifier is similar to that of a parallel RLC circuit having the same Q. The time constant of such a circuit is $Q/\pi f$ seconds, where f is the tuned frequency. Taking the extreme case, at a frequency of 1.5 Hz (Q of 10) the characteristic time constant is 2.13 seconds. The time required to reach steady state is several times this figure, and is long enough to interfere with the tuning and level setting processes. Furthermore, any noise impulse accompanying the signal will set up a ringing response which will take a time of this order to decay. As a result, adjustment of the amplifier at very low frequencies is somewhat difficult and requires considerable patience. Obviously, high Q operation should be avoided; a Q of 5 is best suited to low frequency operation in most instances.

3.9 RECORDING

Strip chart recorders are of two types, galvanometric and servo. Galvanometric recorders are current driven devices and typically require either 0.5 mA or 1.0 mA of input current for full scale deflection. A single-ended recorder output, suitable for driving such recorders, is located on the rear panel of the Model 121. The output signal is applied to the red binding post at an impedance which can be varied from 7 kilohms to 22 kilohms with the associated adjustment. This range of impedance is sufficient to enable full scale deflection of either 0.5 mA-0-0.5 mA recorders (resistance less than 13 k) or 1.0 mA-0-1.0 mA recorders (resistance less than 3 k), when the Model 121 output is full scale. The black binding post (spaced 3/4 inch from the red binding post to accept a standard double banana connector) is grounded to the chassis. To calibrate such a recorder, simply obtain full scale output and adjust the Recorder Adjust Control for corresponding deflection on the recorder. One convenient method of so doing is to adjust the Zero Suppress Control for full scale output (Meter/Monitor Switch set to "OUT").

Servo type recorders are usually high-input-impedance, voltage-sensing instruments, and as such, may be driven either from the front panel Monitor Jack (4.7 k), or from the rear panel Recorder Output Binding Post (7 k to 22 k) with little error caused by drop across the Model 121 output impedance. If one of the recorder sensitivity ranges is 10 V for full scale deflection, an ex-

act correspondence between the panel meter indication and the recorder deflection is easily obtained. If one of the recorder sensitivity ranges is 1 V for full scale deflection, correspondence between panel meter and recorder deflection is even achieved with the Meter/Monitor Switch set to "OUT X10". Should it happen that the recorder one intends to use does not have compatible ranges, or is a high sensitivity recorder without selectable ranges, it will be necessary to install an appropriate shunt resistor across the input terminals of the recorder to realize the desired sensitivity. It might be mentioned that if a high input impedance recorder is connected to the rear panel Recorder Output, the Recorder Adjust Control will have no noticeable effect. With a shunt resistor installed, the range of the control may be increased sufficiently to allow it to serve again as a recorder deflection control.

NOTE: For all Meter/Monitor positions except "OFF", the Recorder Output carries the same signal as is indicated by the meter. When the Meter/Monitor Switch is set to "OFF", the recorder output continues to carry the same signal as if the Meter/Monitor Switch were set to "OUT"; only the meter and Monitor Jack are disconnected.

3.10 ZERO SUPPRESS

Occasionally one may be interested in both the absolute value of a signal and its amplitude variation with time. The Zero Suppress Control of the Model 121 gives the capability of "expanding" these small variations by providing a calibrated suppress with a range of ±10 times full scale output. Consider the following example. Suppose one has a 70 microvolt rms signal. Assuming this signal is measured on the 100 microvolt sensitivity range, the resulting meter indication with the Meter/Monitor Switch set to "OUT" would be 70% of full scale. To examine small variations in this signal, first select the suppress polarity with the Zero Suppress Switch (center position disconnects the Zero Suppress Circuit), and then adjust the Zero Suppress Dial for a meter indication of zero. In the present case, assuming the initial deflection was to the right, the Zero Suppress Switch would be set to "+" and the Zero Suppress Dial, after being adjusted for zero on the meter, would indicate 0.70. If the Meter/Monitor Switch were then set to "OUT X10", plus and minus full scale deflection would correspond to an input signal level change of plus and minus ten microvolts. However, expanding the sensitivity in this manner affects only the meter sensitivity; that is, the range of the Monitor and Recorder Outputs would still be plus and minus 100 microvolts full scale relative to the input.

A better method is to retain the "OUT X1" position of the Meter/Monitor Switch and change the selected sensitivity from 100 microvolts to ten microvolts. Then reset the Zero Suppress Dial to re-establish null. The setting in this case would be 7.00 and the range of all three outputs (Meter, Monitor Jack, and Recorder Output) would be plus and minus ten microvolts. If the Meter/Monitor Switch were then set to "OUT X10", a further gain in meter sensitivity (and only meter sensitivity) from plus and minus ten microvolts to plus and minus one microvolt would be achieved.

Needless to say, this sensitivity could be even further expanded by increasing the gain of the recorder. If, after setting the Meter/Monitor Switch

to "OUT X10", one were to use a recorder with a sensitivity of plus or minus one volt for full scale deflection instead of plus or minus ten volts, the range of the recorder relative to the input signal would be plus and minus one microvolt. As the recorder sensitivity is increased, however, the DC drift of the instrument becomes significant (DC output stability specification is 0.1% of full scale per 24 hours, constant ambient temperature) and directly limits how far the gain can be expanded in this manner.

Finally, it should be pointed out that the Zero Suppress is effective for all settings of the Meter/Monitor Switch, and so can be used to inject offset in any of these "modes", if desired.

3.11 OVERLOAD

Three different types of overload can occur in the Model 121 Lock-In Amplifier. Because the front panel Overload Light warns of only one type of overload, and all three can seriously degrade the accuracy of a reading, the operator should check for each and take corrective action if overload is found to exist. Among the factors which determine the signal level required to produce each type of overload are the frequency of the individual components, whether or not they are coherent with the reference, and, if coherent, what their phase relationship is relative to the reference. Each type of overload, along with the appropriate check and corrective action for each, is discussed in the following paragraphs.

INPUT OVERLOAD

The easiest way to check for overload in the input amplifiers is to monitor the input signal with an oscilloscope. If the peak-to-peak amplitude of the composite input signal does not exceed 450 times the selected sensitivity, this type of overload does not exist. If the observed signal exceeds this limit, select a less sensitive range. If the interfering signal is at a single frequency or over a band of frequencies sufficiently removed from the frequency of the signal of interest, it may be possible to filter out the interfering signal before the lock-in amplifier. By so doing, the selected sensitivity would be dictated only by the amplitude of the frequency of interest, and not by high-amplitude interfering signals which are overloading the circuits preceding the Tuned Amplifier. Consider two examples. For the first, assume a 1 mV signal (rms) accompanied by broadband noise with a peak-to-peak amplitude of 1 V. With regard to the signal of interst, the Sensitivity Switch should be set to "1 mV". However, because the level of the accompanying noise is sufficient to cause overload, the Sensitivity Switch must be set to "5 mV". The input noise tolerance in this position is 2.2 V peak-to-peak, well above the amplitude of the input noise. By setting the Sensitivity Switch to "5 mV", one is assured of an accurate measurement. The reduced output can be compensated for by monitoring the output with a more sensitive meter or recorder. For the second example, assume the same initial conditions except that the noise in this case is concentrated at a frequency far from the tuned frequency. In this case, by inserting the appropriate high- or low-pass filter, the overload can be prevented, allowing the use of the "1 mV" sensitivity range. It should be noted that an appropriate filter could have been of considerable value in the first example as well.

TUNED AMPLIFIER/MIXER OVERLOAD

The Mixer and output stages of the Signal Tuned Amplifier overload at about the same level. Consequently, the Overload Light, which, in effect, indicates the tuned amplifier output level, provides adequate warning of overload in these circuits. If the Overload Light comes on, simply rotate the Sensitivity Switch clockwise until the light goes out.

There are two types of signals which can cause the Overload Light to come on. The first is noise or interfering sinusoids in the pass-band of the tuned amplifier, and the second is coherent signal in quadrature with the signal of interest. Noise at the tuned frequency and quadrature signal* with a peak-to-peak amplitude greater than 250 times the selected sensitivity will cause the Overload Light to come on. Noise components removed from the tuned frequency must be larger to light the Overload Light. The pass-band width is a function of Q. Consequently, in some instances, such as where the Overload Light is "flickering" and is not "hard on", non-overload operation may be restored simply by increasing the Q.

OUTPUT AMPLIFIER OVERLOAD

There are three sources of output amplifier overload. Of the three, the most common, and easiest to detect, is that produced when the rms amplitude of the signal of interest exceeds the selected sensitivity. The resulting off-scale meter deflection clearly indicates this type of overload; consequently, it should not generally be a problem. The second source is input noise components at the tuned frequency. Although the output contribution of such components averages to zero, individual excursions can exceed the range of the output amplifier. To check for such overload, simply observe the signal at the Monitor Jack with an oscilloscope (Meter/Monitor Switch set to "OUT" or "OUT X10"). If noise peaks are observed which exceed plus or minus fifteen volts with respect to ground, increase the Time Constant until these limits are no longer exceeded. The final source is high amplitude quadrature components. As with the tuned frequency noise, one need only increase the Time Constant to prevent the output voltage excursions from exceeding plus or minus fifteen volts with respect to ground.

3.12 HARMONIC SENSITIVITY

Coherent signals which are harmonically related to the input signal contribute to the output indication and will generally degrade that indication at levels well below those required to cause overload. Primarily, error due to harmonic response is introduced in the Mixer. Furthermore, it can be shown that the response of the Mixer (or any other Phase Sensitive Detector) to a given harmonic is exactly proportional to the amplitude of the corresponding Fourier component in the reference waveform. It follows that, because the reference to the Mixer is a symmetrical square wave (this "squaring" is done internally), the Mixer should be immune to even harmonics. However, the symmetry of the reference waveform is not perfect and the effects of even harmonics cannot be ignored.

*See paragraph 3.13 (Quadrature Sensitivity)

To see how a given harmonic will affect the output indication, two basic factors must be considered. The first is the response of the Signal Tuned Amplifier to the harmonic and the second is the Mixer response to the harmonic. In general, the Signal Tuned Amplifier sharply attenuates the harmonic. That harmonic signal which "gets through" the Signal Tuned Amplifier then contributes to the output indication to the degree governed by the Fourier makeup of the Mixer reference signal. Figure III-2 shows the normalized frequency response of the Signal Tuned Amplifier for three different Q settings. The tuned frequency is "f_o" and the frequency of interest (the harmonic) is "f". A glance at the curves shows, for example, that, at a Q of ten, the response to the second harmonic is approximately .07 of its response to the fundamental.

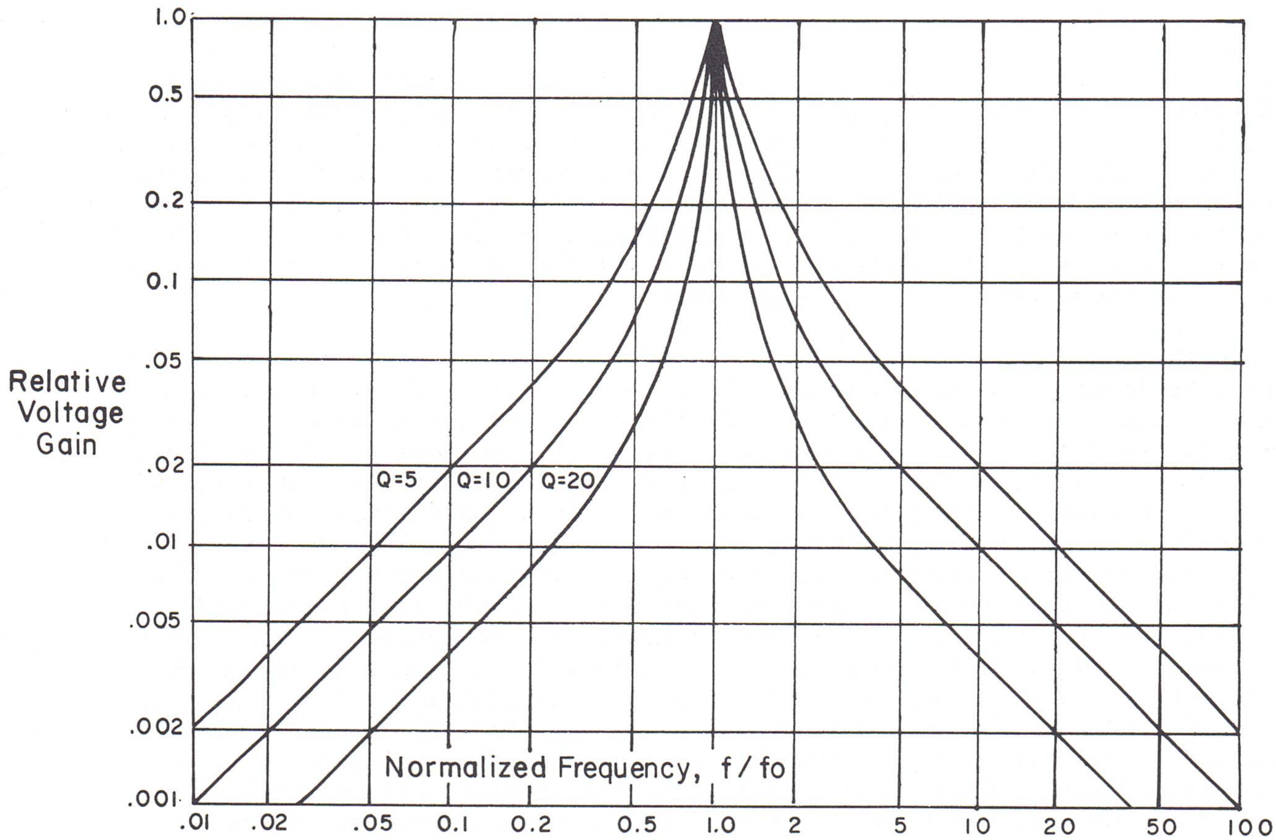


Figure III-2. TUNED AMPLIFIER RESPONSE AS FUNCTION OF NORMALIZED FREQUENCY AND Q

How one determines the response of the Mixer to a given harmonic depends on whether the harmonic is even or odd. For odd harmonics, the response relative to the fundamental response is simply 1/n, where "n" is the number of the harmonic. For example, the third harmonic response is 1/3 the fundamental response, the fifth is 1/5 the fundamental response, etc. In the case of even harmonics, the response is a function of the symmetry of the

reference and is given by the expression:

$$y = \frac{1}{n} \sin \left[n(1 + \epsilon)\frac{\pi}{2}\right],$$

where "y" is the response relative to the fundamental response, "n" is the number of the harmonic, and "ϵ" is the fractional departure of the "half period" from half the period. If n is even and $n\epsilon$ is very much smaller than one, the expression simplifies to:

$$|y| \cong \frac{\pi}{2} \epsilon .$$

In other words, the response to all even harmonics is about the same and is determined by the symmetry of the reference signal. In general, a given half-cycle of the Mixer reference signal will be within 2% of half the period, giving .02 as the value of ϵ. Inserting this number into the formula, one obtains as a "working" value Mixer response to even harmonics, 3.14×10^{-2}. If one is using the "EXT." Mode, ϵ will be determined primarily by the symmetry of the applied reference signal. In all other modes, only internally produced non-symmetry need be considered.

With the above information, one can easily calculate the instrument response to a harmonic of known amplitude. For example, assume that the second harmonic component of an input signal is 100 times the amplitude of the fundamental, that is, quite large but still below the overload limit. At the output of the Signal Tuned Amplifier, assuming a Q of ten, the harmonic will be approximately seven times the amplitude of the fundamental, as can be readily determined by referring to Figure III-2. Multiplying this number by .03, the "working" value of the Mixer even harmonic response, one obtains .21. In other words, the second harmonic will produce an error of 21% in the output indication. In the case of low-order odd harmonics, even lower levels can cause significant errors. For example, assume that the third harmonic component is ten times the fundamental amplitude. From Figure III-2, the amplitude of this harmonic at the output of the Signal Tuned Amplifier will be about 4/10 the fundamental amplitude. Multiplying this number by 1/3, the Mixer response to odd harmonics, one obtains .13, indicating an output error of 13%. It should be mentioned that these examples assume the worst possible phase-relationship between the harmonic and the reference signal. Practically encountered phase relationships are not usually worst case, and the true error will be smaller than the computed error.

A related problem is that of errors resulting from sub-harmonic components of the input signal. Sub-harmonic signals do not <u>directly</u> contribute to the output indication, that is, the Mixer does not respond to them. However, if these signals are present, they will cause severe error at much lower levels than will the harmonics. This results from distortion to the sub-harmonics by the pre-mixer amplifiers. Such distortion consists of the amplifiers generating harmonics of the original sub-harmonic signal, and because these "generated harmonics" can be at the fundamental or tuned frequency, large am-

plitude errors are readily introduced.

Although sub-harmonics are not generally a significant component of the input signal, there is one type of measurement where they must be considered, and that is in the measurement of the harmonic content of a given signal. In such a measurement, the harmonic of interest must be regarded as the "fundamental" at the tuned frequency, and the original input fundamental must be regarded as a large-amplitude sub-harmonic. For a discussion of harmonic measurements, see paragraph 3.15 (HARMONIC MEASUREMENTS).

3.13 QUADRATURE SENSITIVITY

In principle, quadrature signal does not contribute to the output if the Phase Controls are properly set. Practically, it is very difficult to be assured that a large quadrature signal does not constitute a serious source of error. Because it is impossible to determine whether an observed output results from the signal of interest or from interfering quadrature signal, one can not generally properly set the Phase Controls and hence make accurate measurements if the input contains large amplitude quadrature interference. Even relatively small phase setting errors can produce a large "false" output, as indicated in Figure III-3. For example, if the rms amplitude of the quadrature component is ten times the selected sensitivity, a phase setting error of only 1° will yield an output of approximately 17% of full scale.

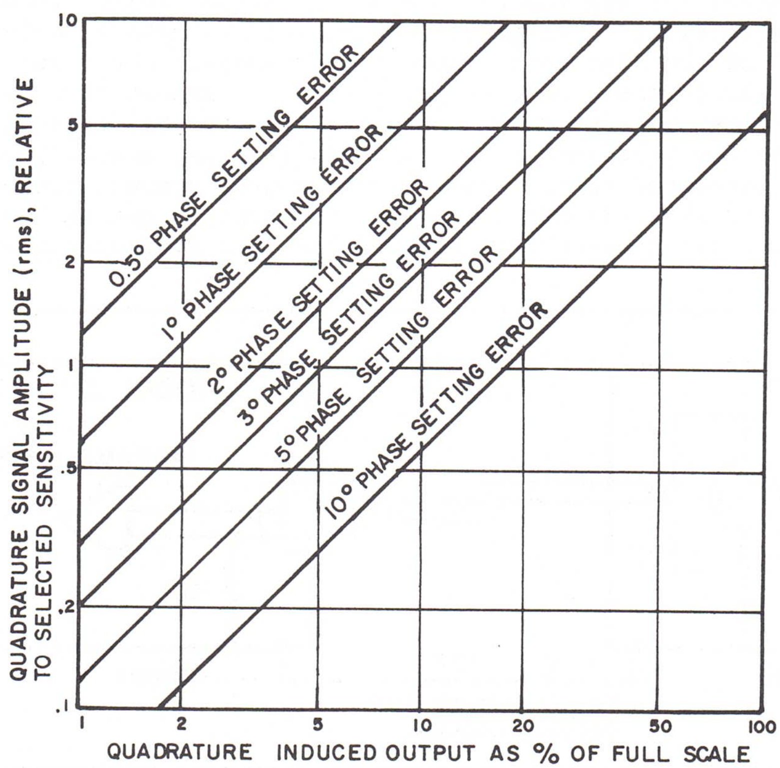


Figure III-3. QUADRATURE SENSITIVITY AS A FUNCTION OF PHASE SETTING ERROR

If, of course, it is possible to "turn off" the signal of interest while continuing to apply the quadrature signal, the Phase Controls can be properly adjusted for zero output. When the signal of interest is turned back on, there will be no possibility of quadrature induced error. Another solution might be to null the quadrature signal at the input of the lock-in amplifier, using another signal of equal amplitude but 180° out-of-phase. If such a nulling signal were available, one could tune the lock-in amplifier to the quadrature signal and then adjust the nulling signal as necessary to obtain zero output. By then rotating the Quadrature Selector one step, the lock-in amplifier would "automatically" be tuned to the signal of interest. One could then adjust the Phase Control for peak meter indication and take the reading in the usual manner.

3.14 GROUNDING

Because the input signal ground of the Model 121 is separated from chassis ground by ten ohms, the instrument can "assume" the ground of the signal source, thereby minimizing the likelihood of errors arising from ground-loop currents. To achieve proper grounding, the outer conductor of the Model 121 "SIG. IN" Jack should be connected to the lowest level signal ground, that is, the ground at the source of the experimental signal. This connection is normally supplied by the outer conductor of the signal cable.

As an additional precaution, there should be a low impedance path between the chassis of the Model 121 and the chassis of the signal source (presumably at source ground potential). This ground connection is normally made by way of the "third wire" of the line cord. However, it happens occasionally that the quality of this third-wire ground is questionable. Should this be the case, connect a heavy gauge wire or ground strap between the two chassis to establish the required low impedance path. If this is done, and if the Model 121 input ground is connected to the lowest level source ground, ground loop currents should not be a significant source of error in making low level measurements. Figure III-4 shows the ground paths in a typical situation.

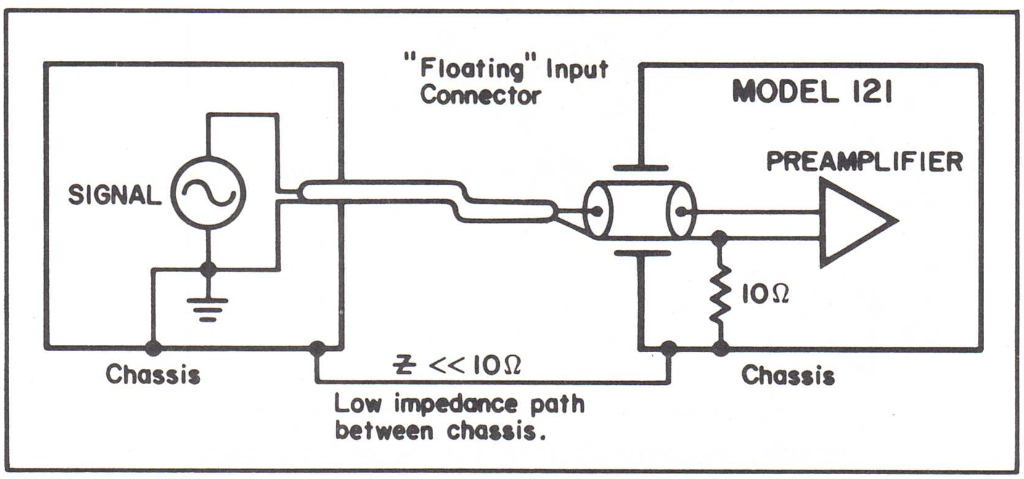


Figure III-4. GROUNDING THE MODEL 121

3.15 HARMONIC MEASUREMENTS

Among the uses to which the Model 121 can be put is measurement of the harmonic content of an input signal. The primary factor which determines how small the amplitude of a harmonic can be and still yield a valid measurement is the quantity of coherent harmonic signal generated internally due to distortion of the applied fundamental. In the case of the Model 121 Lock-In Amplifier, if the fundamental is no more than fifty times the selected sensitivity, second and third harmonics as low as 0.5% can easily be measured.

If one has means of inserting a notch filter to remove the fundamental before applying the signal to the Lock-In Amplifier, highly accurate distortion measurements of extreme sensitivity can easily be made. A notch filter particularly suitable for distortion measurements is the PAR Model 110 Tuned Amplifier/Oscillator. By using this instrument to notch out the fundamental, distortion levels as low as .001% can be measured.

The "EXT. f/2" Reference Mode is particularly useful for making second harmonic measurements because the same signal can be used to drive the Signal and Reference Inputs. If a notch filter is used, the Reference Input Signal should be taken from a point before the notch filter. In making third harmonic measurements, one can use the "SEL. EXT." Mode if the Reference Signal is a square wave at the frequency of the fundamental. The high third harmonic component of the square wave will allow the Reference Channel to be tuned exactly the same as if the Reference Signal were a sine wave at the tuned frequency.

3.16 REAR PANEL SOCKETS

Two rear panel sockets are provided, one of which has eight pins and the other eleven. Several different signals and power supply outputs are provided at the two sockets as indicated in Table III-1 on the following page.

Of the "signals" available, two of them, the 90° and 0° outputs of the Reference Tuned Amplifier, are at a DC level of approximately +10 V. The output of the Signal Tuned Amplifier is at a DC level of approximately +16 V. The DC level at the Reference Input to the Mixer varies, according to the combination of Reference Mode and position of the Meter/Monitor Switch.

3.17 PHASE DETECTOR AND PHASE METER OPERATION

INTRODUCTION

When the Meter/Monitor Switch is in the "PHASE" position, the instrument functions as a Phase Detector and the output is independent of input signal amplitude variations. To use the instrument as a Phase Detector, the input and reference signal must be supplied in the usual manner. However, instead of adjusting the Phase Controls so that the signals applied to the Mixer are in-phase or 180° out-of-phase (the case in lock-in operation), the Phase Controls are adjusted such that the two Mixer inputs are in quadrature. With quadrature inputs, the Mixer output is zero. If, however, there should occur any phase shift of the input signal, the quadrature relationship will no longer exist and the Mixer will give a non-zero output. This output can be of either

EIGHT PIN SOCKET		
PIN	CONNECTION	LOAD LIMIT
1	Signal Tuned Amplifier Output	10 k
2	+33 V (unregulated)	75 mA
3	Not Used	
4	-33 V (unregulated)	75 mA
5	+24 V (regulated)	75 mA
6	Chassis Ground	
7	-24 V (regulated)	75 mA
8	0° Output of Reference Tuned Amplifier	10 k

ELEVEN PIN SOCKET		
PIN	CONNECTION	LOAD LIMIT
1	Chassis Ground	
2 and 7	C_1 (external time constant capacitor)	
3 and 6	C_2 (external time constant capacitor)	
4 and 5	C_3 (external time constant capacitor)	
8	90° Output of Reference Tuned Amplifier	
9	Not Used	
10	Reference Input of Mixer	10 k
11	Chassis Ground	

Table III-1. REAR PANEL SOCKET CONNECTIONS

polarity depending on the direction of the phase shift. If the phase shift is such that the input signal leads the reference signal, the output will be positive. If it lags the input signal, the output will be negative. Following amplification and smoothing in the usual manner, this DC signal drives the panel meter and is also supplied to the Recorder Output. Because both Mixer inputs are square waves when the Meter/Monitor Switch is set to "PHASE", the output per unit phase deviation is linear. This in contrast to lock-in operation where the output varies with the cosine of the phase angle between the Mixer inputs. Normally, in phase detector operation, this output is applied to some external control loop to automatically adjust the phase and maintain the quadrature or null state at the Mixer input.

The sensitivity of the Phase Detector is a function of the noise accompanying the input signal. If the input noise-to-signal ratio does not exceed one, the output varies linearly from zero to nine volts (maximum possible output with the Meter/Monitor Switch set to "PHASE") as the phase at the Mixer shifts from 90° to 0° (or 180°). However, if the input signal is more noisy, the sensitivity decreases; the output per unit phase shift is less than with quieter signals. Still, zero output takes place when the Mixer input signals are in quadrature, and the decreased sensitivity may not degrade the usefulness of the instrument as a Phase Detector in a control loop.

Secondarily, the instrument can also function as a direct reading phase meter when the Meter/Monitor Switch is set to "PHASE". With noiseless signals, the angle can be read directly from the panel meter. With noisy input signals, the reduced phase sensitivity requires that the angle be read from the Phase Dial setting by noting the dial setting required to reduce the panel meter indication to zero. Use of the instrument as a Phase Detector and as a Phase Meter is discussed in the following paragraphs.

PHASE DETECTOR

In general, operation as a Phase Detector can be broken down into the following steps.

(1) Determine the reference mode appropriate to the experiment, connect the reference signal, and optimize the setting of each reference control. Exactly the same considerations apply as for lock-in operation.

(2) Calibrate the "phase zero", that is, ascertain that a signal which is in-phase with the external reference signal will yield a panel meter indication of 0°. The easiest way to obtain an in-phase signal is supply the reference signal simultaneously to the Reference and Signal Channels. NOTE: If the phase between the input and reference signals is to be other than 0°, a separate phase-zero calibrate signal at the proper phase angle will have to be externally derived and this procedure appropriately modified. With the Reference Signal applied to both inputs, set the Meter/Monitor Switch to "PHASE", the Phase Quadrant Switch to "+90°", and the Phase Control to "0°". The Sensitivity is not too critical, a setting of about 1/10 the peak-to-peak amplitude of the applied signal being about right. At this time the panel meter should indicate 0°. If it does not, it is an indication that the Signal Channel is not tuned to exactly the same frequency as the Reference Channel, and, as a result, is introducing unwanted phase shift. To tune the Signal Channel to the same frequency, simply adjust the Frequency Trim Control for a panel meter indication of 0°. If one were operating in the "EXT." Reference Mode, it might be necessary to change the setting of the Main Tuning Dial to get within the adjustment range of the Frequency Trim Control. As in lock-in operation, the Q should be determined and set in advance of any calibration measurement.

(3) Remove the reference signal from the "SIG. IN" Jack and connect instead the input signal.

(4) Select the sensitivity appropriate to the input signal. To select the optimum sensitivity, some knowledge of the nature of the signal is required. Factors to be considered include the approximate signal amplitude, amplitude variations, and the amplitude of any noise accompanying the input signal. As a general rule, it is preferable to operate at a higher-than-necessary sensitivity (providing one stays within the overload limits) than to operate with insufficient sensitivity. Sensitivity considerations for several possible input signals follow.

(a) Noiseless Signal, No Amplitude Variation

The optimum sensitivity equals the rms value of the fundamental component of the input signal. Higher sensitivities, within the overload limits as indicated by the Overload Light, can be used.

(b) Noiseless Signal, Signal Amplitude Variation

The optimum sensitivity equals the minimum rms value of the fundamental component of the input signal. Higher sensitivities, within the overload limits as indicated by the Overload Light, can be used. Note that the allowable maximum-signal to minimum-signal ratio is limited to 100:1, the overload point.

(c) Signal With Noise, No Signal Amplitude Variation

The optimum sensitivity equals the rms value of the fundamental component of the input signal. If this amplitude is unknown, it can easily be determined by using the Model 121 as a Lock-In Amplifier. Higher sensitivities, within the overload limits as indicated by the Overload Light, can be used. However, in this case one must also be concerned with overload of the input amplifiers as well, and this type of overload will not turn on the Overload Light. The best protection against input overload is to examine the input signal with an oscilloscope and ascertain that the peak-to-peak amplitude of the composite input signal never exceeds 450 times the selected sensitivity.

(d) Signal With Noise, Signal Amplitude Variation

The optimum sensitivity equals the minimum rms value of the fundamental frequency component of the input signal. The same overload considerations apply here as apply to "(c)" above.

(5) Connect the output of the Model 121 to the external control loop. The panel-meter should indicate 0° when proper phase-lock operation is established. However, a panel-meter indication of 0° does not necessarily mean that proper phase-lock has occurred. Because the Time Constant and Roll-off Rate Switches govern the response speed, their setting will be instrumental in determining the overall loop stability. However, external factors must also be considered. Achieving a stable control loop can be difficult. The criteria to be considered are beyond the scope of this manual and the reader is referred to any of the standard texts on phase-lock loop control.

PHASE METER

As mentioned in the introduction, the instrument can be used to measure the angle (θ) of the input signal relative to the reference signal. In general, the following procedure can be used to make a phase measurement.

(1) Carry out steps 1 through 4 of the preceding Phase Detector Proce-

dure. In performing step 2, use the reference signal as the phase-zero calibration signal. In other words, the note of step 2 is not relevant to phase-meter operation.

(2) Determine the quadrant of the input signal by noting the polarity of two readings known as the "A" polarity reading and the "B" polarity reading. In carrying out the preceding step, the Phase Control should have ended up set to "0°" and the Phase Quadrant Selector to "+90°". Assuming this is the case, note the polarity of the panel meter indication. This is the "A" reading. Then set the Phase Quadrant Switch to "0°" and again note the polarity of the panel meter indication. This is the "B" reading. Determine the quadrant from the noted polarities as follows.

If A is positive and B is positive, then θ is in quadrant 1
If A is positive and B is negative, then θ is in quadrant 2
If A is negative and B is negative, then θ is in quadrant 3
If A is negative and B is positive, then θ is in quadrant 4

After determining the quadrant, reset the Phase Control to "0°" and the Phase Quadrant Selector to "+90°".

(3) If θ is to be determined from the meter, simply note and record the panel-meter indication (ϕ), which indicates linearly from -90° to +90°.

The angle of the input signal (θ) relative to the reference can then be determined by referring to Figure III-5.

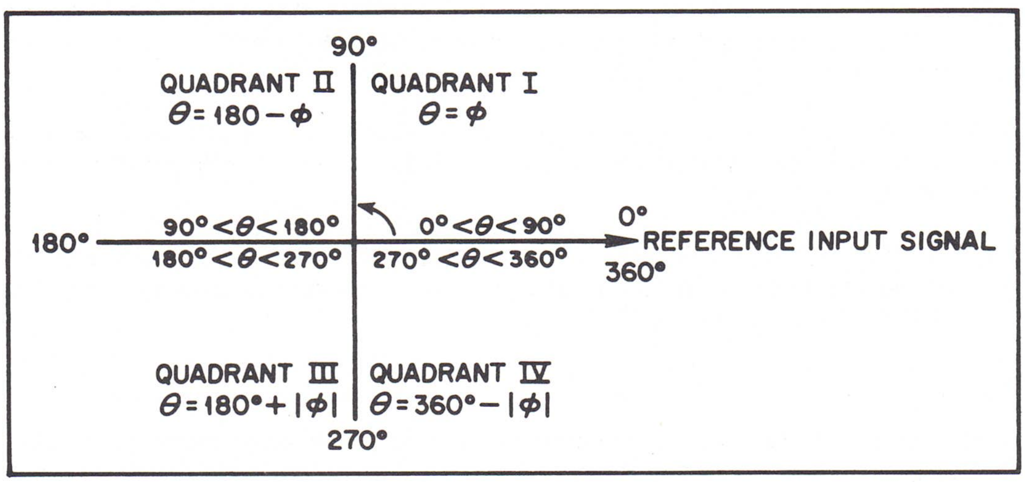


Figure III-5. DIRECT PHASE MEASUREMENT

(4) To measure θ by nulling, proceed as follows according to the determined quadrant.

(a) Quadrant 1

Adjust the Phase Dial for zero meter indication. The angle θ is given directly by the dial setting.

(b) Quadrant 2

Set the Phase Quadrant Selector to "180°". Then adjust the Phase Dial for zero meter indication. The angle θ is the indicated angle plus 90°.

(c) Quadrant 3

Adjust the Phase Dial for zero meter indication. The angle θ is the indicated angle plus 180°.

(d) Quadrant 4

Set the Phase Quadrant Selector to "180°". Then adjust the Phase Dial for zero meter indication. The angle θ is 270° plus the dial indication.

(5) Angles of 0°, 90°, 180°, and 270° are special cases because they border on two quadrants. They can be identified from the meter indication as follows.

(a) If the indicated angle is 0°, and setting the Quadrant Selector to "0°" yields a positive indication (90° indication with noiseless input signal), θ is 0°.

(b) If the indicated angle is 0°, and setting the Quadrant Selector to "0°" yields a negative indication (-90° indication with noiseless input signal), θ is 180°.

(c) If the indicated angle is positive (90° with noiseless input signal), and the indication goes to zero if the Quadrant Selector is set to "0°", θ is 90°.

(d) If the indicated angle is negative (-90° with noiseless input signal), and the indication goes to zero if the Quadrant Selector is set to "0°", θ is 270°.

RECORDING

Phase variations with time can be recorded in much the same manner as amplitude variations. All phase recordings, however, must be made from the rear panel Recorder Output because the signal limiter output signal and not the meter analog voltage is available at the Monitor Jack when the Meter/Monitor Switch is set to "PHASE". This limiter output is essentially a symmetrical square wave at the input signal frequency. If the input signal is noisy, the leading and trailing edges of the square wave will appear as regions of random transients. With increased noise, the signal becomes more and more ob-

scured. The limiter output signal has a peak-to-peak amplitude of approximately 85 mV and it is at a DC level of +1.5 V. The degraded phase sensitivity with very noisy input signals will of course affect the accuracy of the recording.

ZERO SUPPRESS

The Zero Suppress feature of the instrument is generally not used during Phase Measurements because no increase in phase sensitivity is obtainable. The Zero Suppress Switch is normally left in the center (off) position. If for some reason a non-zero reference level at the output were desired, the Zero Suppress Control could be used to provide the desired offset.

3.18 AC VOLTMETER OPERATION

In addition to operating as a Lock-In amplifier or Phase Detector, the Model 121 can function as a tuned AC voltmeter. Despite the degraded noise rejection capabilities as compared to Lock-In operation, tuned amplifier operation is simpler, and, where the noise is significantly lower than the signal level, or concentrated in bands well removed from the signal frequency, may yield equivalent performance.

Operation as an AC voltmeter can generally be broken down into the following sequence.

(1) Set the Meter/Monitor Switch to "SIG." to transfer the instrument to tuned amplifier operation.

(2) Select the desired operating Q and calibrate the gain.

(3) Connect the signal to be measured to the Signal In Jack.

(4) Select the sensitivity appropriate to the signal level and adjust the Frequency Trim Control for maximum meter indication. The meter then indicates the rms amplitude of the input signal over the bandwidth of the tuned amplifier. Full scale meter indication and the selected sensitivity correspond.

Gain calibration for tuned voltmeter operation is easier than for Lock-In operation. After setting the Meter/Monitor Switch to "SIG.", proceed as follows to calibrate the gain.

(1) Set the Mode Switch to "CAL. 10 mV" and the Sensitivity Switch to "10 mV".

(2) Tune to the frequency of interest.

(3) Select the Q at which the measurement is to be made. Because the calibration signal is a square wave, for good rejection of the harmonics and hence an accurate calibration, a Q of ten or higher is recommended. Although gain stability and tuned circuit characteristic time constant influence the choice of Q in much the same manner

as for Lock-In operation, the effect of Q on bandwidth is perhaps more important because the noise bandwidth is determined by Q alone. The Mixer Time Constant serves only to smooth the ouput DC and in no way influences the equivalent noise bandwidth ($f/Q \times \pi/2$, where f is the tuned frequency and Q is that selected). The higher the Q, the less components of the input signal not at the tuned frequency contribute to the output indication.

(4) Connect the Reference In/Out Jack to the Signal In Jack.

(5) Adjust the Frequency Trim Control for peak meter indication.

(6) Vary the "ADJ." Control to obtain full scale meter indication.

Having calibrated the gain at the operating frequency, disconnect the calibration signal and connect instead the signal to be measured. To avoid any possible pickup problems, it is better to leave the Mode Switch in any position other than "CAL. 10 mV" or "INT." After connecting the signal of interest, select that position of the Sensitivity Switch which yields the highest "on-scale" indication. CAUTION: Do not operate with less than 10% of full scale deflection. Minimum signal requirements preclude accurate measurements with less than 10% out. Also, with no input signal applied when operating on the most sensitive ranges, internal noise may cause an output indication of a few percent.

After selecting the appropriate sensitivity range, touch up the Frequency Trim Control for peak meter indication and take the reading. The meter is average responding but rms calibrated.

Tuned amplifier measurements are subject to sources of error which generally do not affect Lock-In measurements. When operating as a Lock-In Amplifier, the instrument responds only to signal which is synchronous with the reference signal. Non-synchronous signal close to the tuned frequency averages to zero and the output level yields the rms amplitude of the tuned frequency component of the input signal. A simple tuned voltmeter, however, cannot reject noise over the tuned bandwidth, and this noise contributes to the output indication. Providing the noise in the passband is small, accurate measurements of the tuned frequency component of the input signal are obtainable.

With the Meter/Monitor Switch set to "SIG.", the output of the Signal Tuned Amplifier is available at the Monitor Jack, allowing the instrument to be used as a tuned amplifier. Assuming the input is a sine wave with an rms amplitude equal to the selected sensitivity, the signal at the Monitor Jack will be a sine wave at the tuned frequency with a peak-to-peak amplitude of approximately 140 mV. This signal is referenced to plus two volts and its source impedance is 4.7 k.

SECTION IV
THEORY AND CIRCUIT DESCRIPTION

4.1 INTRODUCTION

The Model 121 is essentially three instruments in one, the three instruments being: (1) a Lock-In Amplifier, (2) a Phase Detector, and (3) a simple tuned AC Voltmeter. In the following paragraphs, the functioning of the instrument in each of these "modes" will be separately considered, followed by a detailed description of the individual circuits. As a convenience in following these discussions, Figure IV-2 (page IV-3) is provided. By referring to this diagram, one should easily be able to determine the interconnections which are particular to each specific use of the instrument.

4.2 LOCK-IN AMPLIFIER

When operating as a Lock-In Amplifier, the Model 121 constitutes a detection system capable of operating with an extremely narrow equivalent-noise bandwidth. A band of frequencies is selected from the signal spectrum and converted to an equivalent bandwidth about DC. Conversion from AC to DC takes place in the Phase Sensitive Demodulator (Mixer) by synchronous demodulation. The comparison or reference signal can be generated either externally or internally, as explained in Section III.

Referring to Figure IV-2, note that the experimental signal is connected to the "SIG. IN" Jack. From there it is routed through the combination of attenuators and preamplifiers appropriate to the selected sensitivity. These are followed by a decoupling circuit, which in turn drives the Signal Tuned Amplifier. This amplifier passes a band of frequencies centered about the tuned frequency, the actual bandwidth being a function of the selected Q as indicated in Figure IV-1. The output of the Signal Tuned Amplifier and the Reference Signal are both applied to the Mixer, where synchronous demodulation is employed to convert the AC signal to a proportional DC signal. Noise components appear as AC fluctuations in the DC level at the output of the Mixer, which is followed by a DC amplifier. This amplifier has two functions, the first being to amplify the DC signal to the required output level, and the second being to narrow the bandwidth of the output signal to reduce the noise fluctuations to an insignificant level. Because only the synchronous component of the input signal contributes to the average DC level at the output, the Time Constant can be made as high as necessary to reduce the bandwidth to the degree required to "smooth" the output and yield a stable accurate reading.

Note that the Reference Signal is processed in a different manner for each of the reference modes. In the Selective External Mode, the signal applied to the Reference In/Out Jack goes directly to the Reference Attenuator. From there it is fed through a source follower to the Reference Tuned Amplifier, which, regardless of the waveshape of the reference input signal, provides a sine wave output at the tuned frequency. This sine wave is routed to the Phase Shifter Circuits, which allow the phase of the signal to be varied over 360°. From the Phase Shifter, the signal goes to the Schmitt Trigger, which in turn directly drives the Reference Input of the

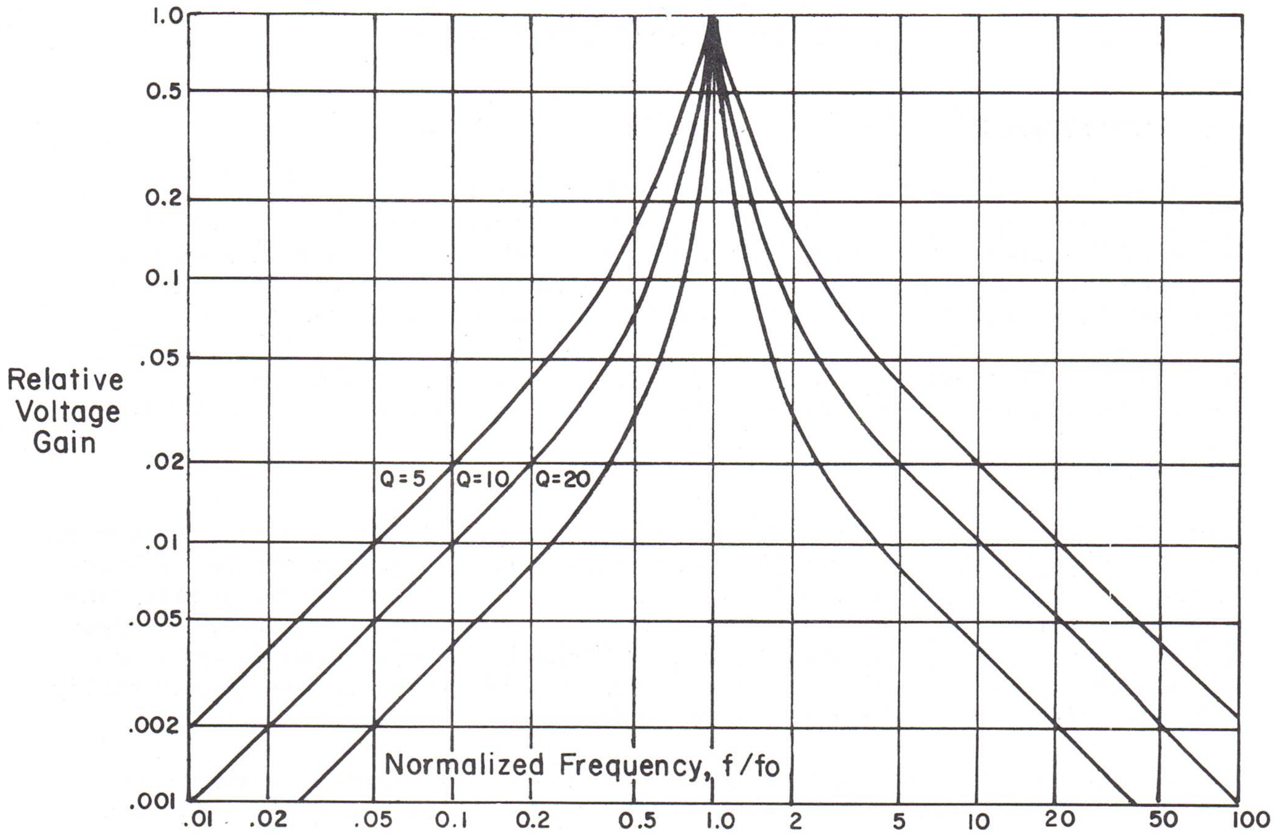


Figure IV-1. TUNED AMPLIFIER RESPONSE AS A FUNCTION OF NORMALIZED FREQUENCY AND Q

Mixer. The "EXT. f/2" Mode differs only in that the Frequency Doubler is interposed between the Reference In/Out Jack and the Reference Attenuator. In the case of the External Mode, the Reference Tuned Amplifier and Phase Shifter are bypassed. If any phasing is required, it must be done externally. In the Internal Mode, positive feedback is applied around the Reference Tuned Amplifier, causing it to oscillate at the tuned frequency. The sine-wave output of this oscillator is supplied to the Reference In/Out Jack by way of the Reference Attenuator and its associated source follower. Finally, in the Calibrate Mode, an accurate square wave produced by the Reference Limiter, a circuit in the positive feedback loop, is available at the Reference In/Out Jack for calibration purposes.

4.3 TUNED AC VOLTMETER

When the Meter Monitor Switch is set to "SIG.", the instrument functions as a simple tuned voltmeter. Referring to Figure IV-2, note that the experimental input signal is processed in much the same manner as in lock-in operation. After being preamplified or attenuated, according to the selected sensitivity, the signal is applied to the variable Q tuned amplifier. As before, the amplifier passes a band of frequencies centered about the tuned

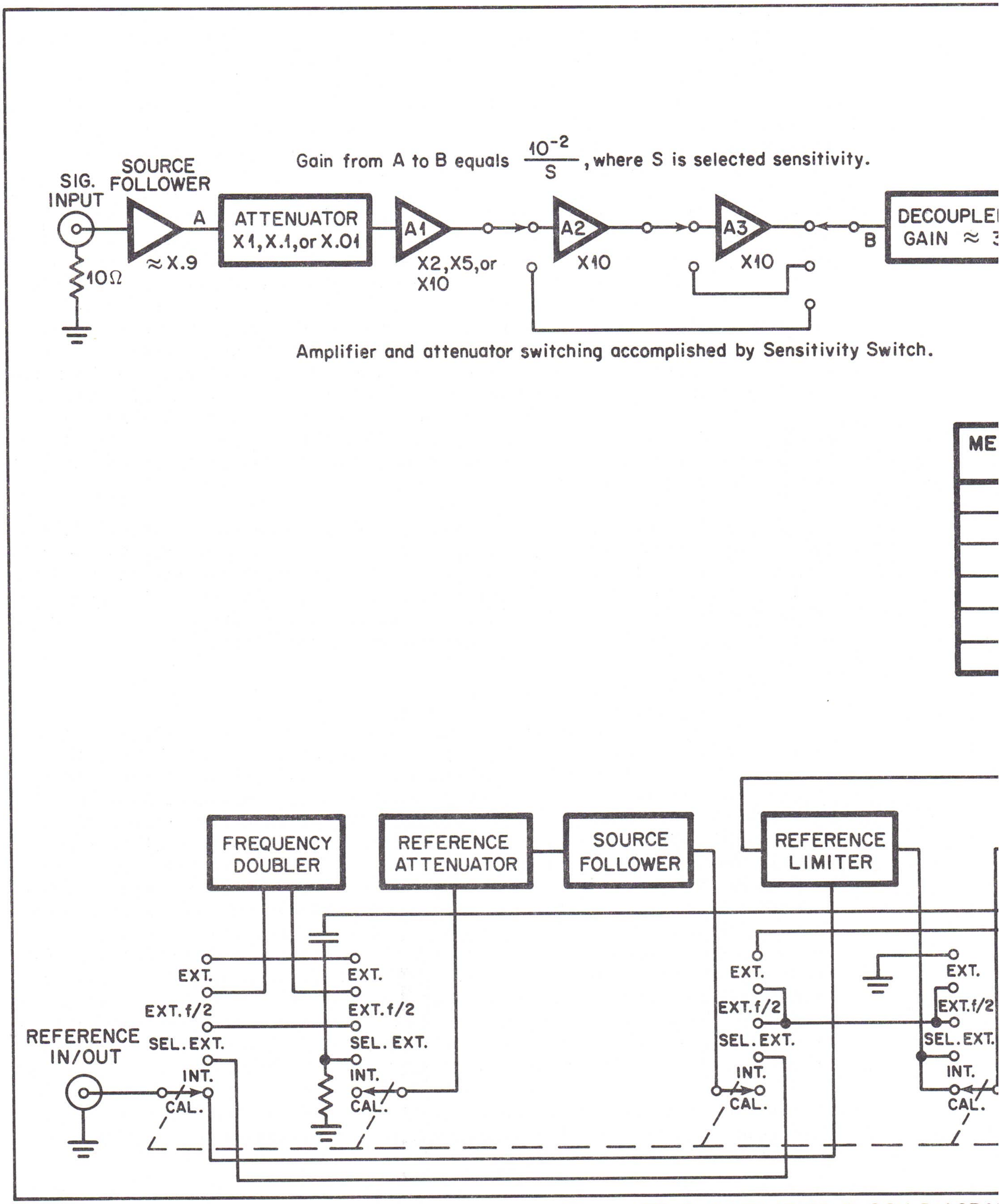
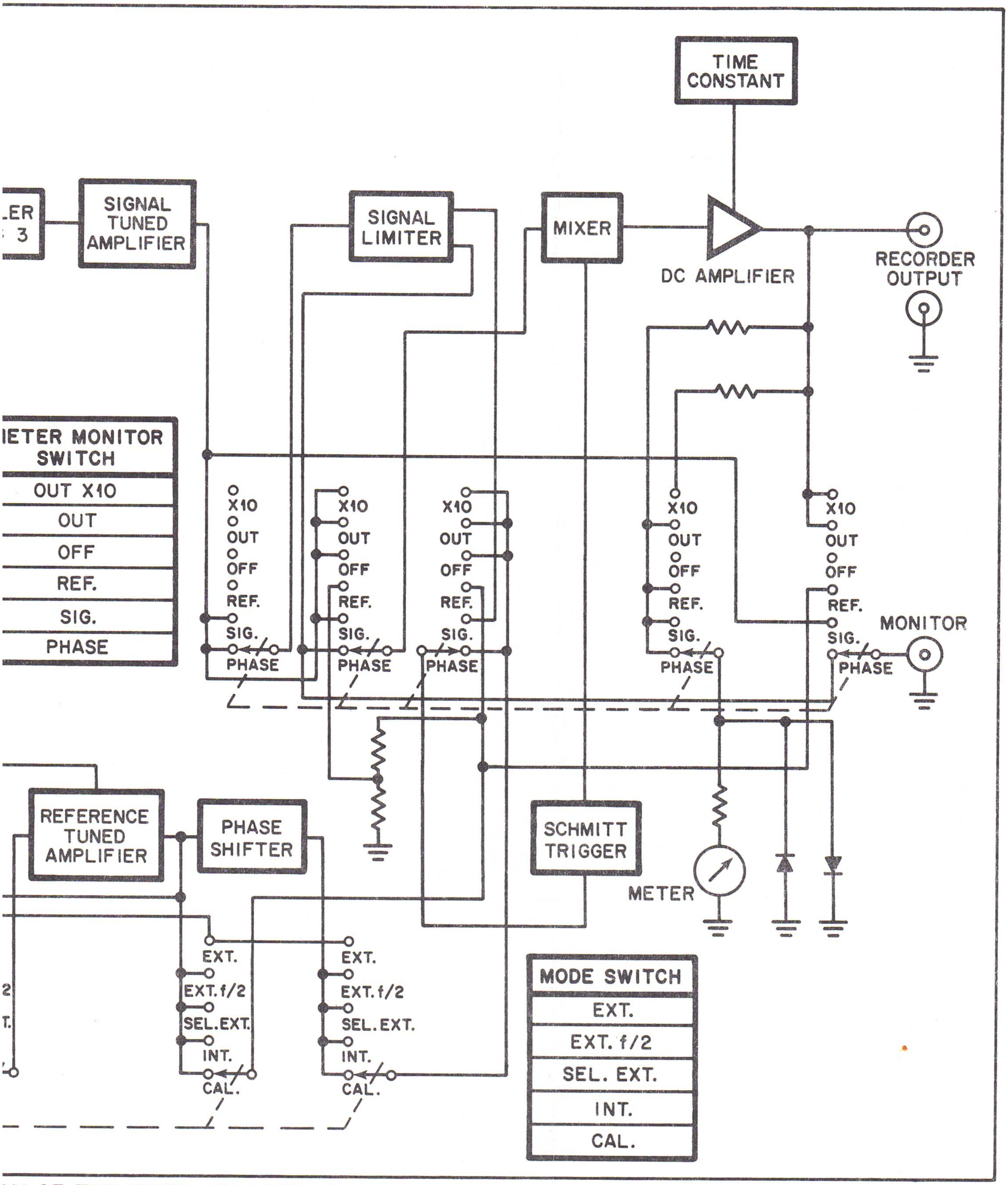


Figure IV-2. SIMPLIFIED BLOCK DIAGRA



AM OF THE MODEL 121 LOCK-IN AMPLIFIER.

frequency, the bandwidth being a function of the selected Q. In addition to driving the signal input of the Mixer, the Signal Tuned Amplifier drives the Signal Limiter, which converts the sinewave input to a square wave at the same frequency. Noise accompanying the signal is also limited. The Signal Limiter then drives the reference input of the Mixer by way of the Schmitt Trigger. Herein lies the fundamental difference between lock-in and ordinary tuned amplifier operation. In lock-in operation, the signal and reference inputs of the Mixer are derived from two separate signals. In tuned amplifier operation, both inputs are derived from the same signal*. To see how this difference affects the noise rejection capabilities of the Model 121, recall that the Mixer responds only to components of its signal input which are synchronous with the reference input. In lock-in operation, noise is not synchronous and so does not contribute to the net Mixer output. In tuned amplifier operation, the noise is synchronous with the reference because both the signal and reference inputs of the Mixer are derived from the same signal. Noise suppression in the Lock-In Amplifier results almost entirely from synchronous rectification of two different signals in the Mixer, the Signal Tuned Amplifier serving mainly to attenuate any harmonics and to reduce the overall noise power relative to the signal of interest. Any noise rejection which takes place in tuned amplifier operation is solely due to tuned filter action of the Signal Tuned Amplifier. All signal components in the amplifier passband, synchronous or non-synchronous, contribute to the output indication.

As in lock-in operation, the DC Amplifier drives the panel meter. Unlike lock-in operation, however, the Monitor Jack is connected, not to the output of the DC Amplifier, but instead to the output of the Signal Tuned Amplifier, allowing the signal there to be observed with an oscilloscope or otherwise monitored. A DC output, analogous to that available in lock-in operation, is available at the rear-panel Recorder Output.

4.4 PHASE DETECTOR

Except that the Signal Limiter "squares" the output of the Signal Tuned Amplifier prior to its application to the signal input of the Mixer, the instrument functions much the same when operated as a Phase Detector (Meter Monitor Switch set to "PHASE") as it functions when operated as a Lock-In Amplifier. As a result of the limiting, changes in the amplitude of the input signal will not cause changes in the amplitude of the Mixer input signal. Consequently, the Mixer (and the instrument) responds only to changes in the phase relationship of the input and reference signals. (By contrast, the Lock-In Amplifier responds to changes in both amplitude and phase.) Regardless of the input phase relationship, the Phase Controls can be used to establish the phase between the two Mixer input signals at 90°, resulting in zero output. Any input phase shift then will yield plus or minus out according to the direction of the shift. This output can be incorporated into an external control loop to maintain the correct phase between the "controlled" signals. Noise accompanying the input signal has no effect other than to decrease the "gain". With noisy signals, less output

*Similarly, when the Meter/Monitor Switch is set to "REF." to monitor the Reference Signal, both the signal and reference inputs of the Mixer are driven by the Reference Signal.

DC is produced for a given phase shift. The null still is maintained when the Mixer input signals are in quadrature, and the usefulness of the phase detector function is in no way degraded.

As mentioned in Section III, the instrument can also be used as a direct reading Phase Meter by appropriately setting the Phase Controls and taking readings by the method appropriate to the existing noise level.

Referring to Figure IV-2, note that the DC Amplifier drives the panel meter and the Recorder Output. However, the Monitor Jack is connected to the output of the Signal Limiter, allowing the signal at that point to be monitored. If the input signal is noise free, the observed signal will simply be a square wave at the frequency of the input signal. If the input signal is somewhat noisy, the leading and trailing edges of the square wave will be blurred by fast random transitions (assuming random noise). As the noise level is raised, the edges become increasingly blurred, until finally the square wave at the signal frequency is entirely obscured. As in lock-in operation, the noise is not synchronous with the reference signal and so does not contribute to the output indication except as fluctuations which average to zero.

4.5 PREAMPLIFIER BOARD

Referring to the schematic on page VIII-3, note that the input signal is applied through capacitor C1 to an attenuator which is followed by a series of amplifiers. According to the position of the Sensitivity Switch, different combinations of attenuation and amplification will be switched into the circuit by contacts of the Switch. Gain control over each consecutive 1, 2, 5 sequence is accomplished by changing the gain of A1, the first Preamplifier. Table IV-1 shows the combination of attenuation and amplification corresponding to each position of the switch.

Sensitivity	Attenuator X1	X0.1	X0.01	Amplifier A1 X2	X5	X10	Amp. A2 X10	Amp. A3 X10	Gain input to A3 out
10 µV	X					X	X	X	1×10^{3}
20 µV	X				X		X	X	5×10^{2}
50 µV	X			X			X	X	2×10^{2}
100 µV	X					X	X		1×10^{2}
200 µV	X				X		X		5×10^{1}
500 µV	X			X			X		2×10^{1}
1 mV	X					X			1×10^{1}
2 mV	X				X				5×10^{0}
5 mV	X			X					2×10^{0}
10 mV		X				X			1×10^{0}
20 mV		X			X				5×10^{-1}
50 mV		X		X					2×10^{-1}
100 mV			X			X			1×10^{-1}
200 mV			X		X				5×10^{-2}
500 mV			X	X					2×10^{-2}

Table IV-1. CIRCUITS SWITCHED IN FOR EACH POSITION OF THE SENSITIVITY SWITCH

Note that the attenuator has three positions, X1, X0.1, and X0.01. Source follower Q1 follows the attenuator and drives Preamplifier A1. Of the four transistors which make up A1, Q101 acts as a constant current source for the pair Q102-Q103, Q102 provides isolation between the input and common base stage Q103, and emitter follower Q104 furnishes a low impedance drive to the following amplifier. The gain of the stage is determined by the ratio of R110 to the resistance between the emitters of Q102 and Q103. As the Sensitivity Switch is rotated, different resistances are connected between points "G1" and "G2", causing the gain to be alternately, two, five, and ten.

Amplifier A2 is similar. The input signal is applied to emitter follower Q105, which drives common base stage Q106. The gain, nominally ten, can be calibrated by adjusting trim-potentiometer R123. Emitter follower Q107 provides a low impedance drive to the following stage. Note that A3 (Q108 through Q110) is identical to A2, and so requires no separate description.

The final signal processing circuit on the Preamplifier Board is the Tuned Amplifier Decoupler, which provides isolation between the preceding amplifiers and the Signal Tuned Amplifier. This circuit consists of an emitter follower, Q117, followed by a common base stage, Q118. Note that the front-panel Sensitivity "ADJ." Control merely allows the resistance between the emitters of Q117 and Q118 to be varied, thereby controlling the magnitude of the signal current in the collector circuit of Q118. It should be mentioned that Q118 drives the emitter of another common base stage, Q206 on the Signal Tuned Amplifier Board, and that the gain, measured from the base of Q117 to the collector of Q206, equals the ratio of the load resistance of Q206 to the resistance between the emitter of Q117 and that of Q118. Furthermore, this gain, nominally three, is obtained at resonance only. At higher and lower frequencies the gain is less. Because of the very low impedance "seen" by the collector circuit of Q118, the voltage amplitude of the signal on this line is very low and not suitable for viewing with an oscilloscope.

The last block of circuitry located on the Preamplifier Board is the Power supply Decoupler (Q111 through Q116). This circuit, which consists of a pair of simple regulators, accepts ±24 V and furnishes the ±15 V used by the Preamplifiers.

Finally, note that the ground for all of these circuits is separated from chassis ground by the ten-ohm resistor R153. As explained in Section III, this ten-ohm ground allows the Model 121 to "assume" the experimental ground, thereby greatly reducing the likelihood of errors due to ground-loop currents when working at low signal levels.

4.6 SIGNAL TUNED AMPLIFIER BOARD

SIGNAL TUNED AMPLIFIER

Referring to the schematic of the Signal Tuned Amplifier (page VIII-4), note that the Preamplifier Board Output is applied to the emitter of common base stage Q206. Taking the signal which appears at the collector of this transistor as the input signal, and that which appears at the collector of Q217 as the output signal, the gain of the Signal Tuned Amplifier at resonance is

one. At frequencies above and below the resonant frequency the gain is lower, as indicated in Figure IV-1.

The Q of the amplifier depends on the setting of the front-panel Signal Q Control, which, by allowing the emitter circuit resistance to be varied, gives a means of controlling the gain of Q203. Because the signals at the base of Q204 null at resonance, Q203 has absolutely no effect at resonance, even though it is directly connected to the line carrying the Preamplifier Board output signal to the emitter of Q206. Away from resonance, as will be shown later, the net signal at the base of Q204 is not zero and Q203 injects signal current into the emitter of Q206. This current opposes the signal developed across R212. The rate of decrease in amplitude of this signal per fractional frequency deviation depends on the gain of Q203. The higher the gain of this stage, the larger the opposing signal will be for a given deviation. In other words, high gain in Q203 gives high Q and a "faster" roll-off.

The component values in the two phase shift networks, each of which provides a phase lag at 45° at the resonant frequency, determine the resonant frequency of the Signal Tuned Amplifier. The Frequency Multiplier Switch determines the size of the capacitive component of the networks, while the Main Tuning Dial governs the resistive component.

Observing the schematic, note that several "phasor" diagrams have been provided, each identified by a number. Because phase shift and phasor addition concepts are helpful in understanding the amplifier, the circuits will be explained in terms of tracing a given signal at the resonant frequency through the amplifier, with appropriate references to the phasor diagrams.

Assume that a signal is available at the output of the Preamplifier Board. This signal will appear as a voltage across R212 in the collector circuit of Q206. Let this signal be used as the "standard" in terms of which the other signals in the circuit will be defined. Also, let this signal be represented by the "unit phasor" (phasor diagram "1"), a phasor of "unit" amplitude and at zero degrees.

Further considering the schematic, note that the unit phasor is applied to the first phase shift network at the emitter of Q207 (phasor diagram "2"). At the output of the network (base of Q208), the signal will be as indicated in phasor diagram "3". It will lag the unit phasor by 45° and have an amplitude of $1/\sqrt{2}$. This signal is applied to the high input impedance, low output impedance amplifier stage consisting of Q208 and Q210. Note also that this stage has a second input. The unit phasor is applied through R219 to the emitter of Q208. The output of the Q208-Q210 stage is applied to common base stage Q209. For purposes of signal flow analysis, these three transistors may be considered as a single transistor, as shown in Figure IV-3. The simplest approach to understanding the circuit is that of superposition, that is, of considering the effect of each of the input signals separately. Observing Figure IV-3, note that the unit phasor input signal is represented by e_2, and that the phase-shifted signal is represented by e_1. First assume that e_1 is zero. The stage then is a common base amplifier, the gain of which is given by the ratio of R221 to R219, or one. The output produced by e_2 is just the unit phasor (phasor "a" in diagram "4").

Now assume e_2 to be zero. The "composite" transistor now acts as an inverting amplifier with a gain of minus two (ratio of R221 to the parallel combination of R219 and R220). The output produced by e_1 can be represented by a phasor (phasor "b" in phasor diagram "4") which leads the unit phasor by 135° and which has an amplitude of $2/\sqrt{2}$. To see what the output is with both inputs applied, the two separate output phasors need only to be added. As indicated in Figure IV-3 and in phasor diagram "4" of the schematic, the resultant phasor leads the unit phasor by 90° and is the same amplitude as the unit phasor.

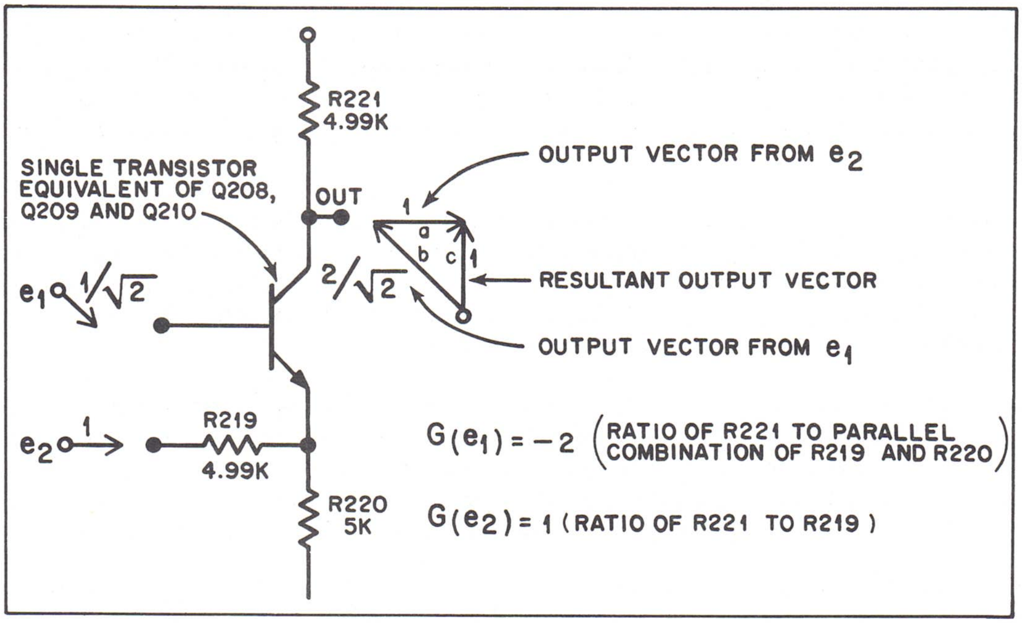


Figure IV-3. SIMPLIFIED VIEW OF PORTION OF SIGNAL TUNED AMPLIFIER SCHEMATIC

This resultant phasor, after passing through emitter follower Q213, is applied to the second phase-shift network where another phase lag of 45° takes place. The signal at the output of this network is represented by a phasor (diagram "6") which leads the unit phasor by 45° and which is $1/\sqrt{2}$ in amplitude. Q214 and Q215 constitute a "complementary Darlington" stage, one output of which is routed through emitter follower Q216 to R234. As indicated by diagram "7", this signal is identical to that at the output of the second phase-shift network; it leads the unit phasor by 45° and is $1/\sqrt{2}$ in amplitude.

Consider again the signal at the base of Q208. This same signal appears at the emitter of Q208 and then at the emitter of Q211 (the low emitter impedance of Q208 assures that the unit phasor signal being applied through R219 will have negligible effect on the signal at the emitter of Q208). Observe that the signal at the emitter of Q211 is applied to R235, and that it is mixed with the signal applied to R234. One of these signals leads the unit phasor by 45°, the other lags the unit phasor by 45°, and both are of equal amplitude ($1/\sqrt{2}$). By superposition and phasor addition, it is apparent that the signal at the collector of Q217, earlier defined as being the output of

the Signal Tuned Amplifier, can be represented by a phasor (diagram "9") in phase with the unit phasor, and of the same amplitude.

Recall that it is essential to the operation of the amplifier that no signal be present at the base of Q204 at resonance. Observing the schematic, note that three different signals are mixed at the emitter of Q205, and that the "net" signal current at this emitter is dropped across R208 to provide the signal which appears at the base of Q204. By assuming the resonant conditions, it can be shown that these three signals null to zero at the resonant frequency (phasor diagram "11").

Considering the signals separately, the first is simply the unit phasor applied through R211 in parallel with the series combination of R209 and R210. It is represented by phasor "c" in phasor diagram "11". The second is produced by inverter Q212 from the signal at the emitter of Q211. This signal is represented by phasor "b" in phasor diagram "11". The third is the inverted output of pair Q214-Q215. This signal is represented by phasor "a" in phasor diagram "11". As indicated in this diagram, the resultant of these three signals at resonance is zero.

Note that current nulling is employed; the impedance looking into the emitter of Q205 is very low, and all three signal currents equal the indicated phasors divided by approximately five kilohms. The resistors which determine the current produced by each phasor are: (1) R211 in parallel with the series combination of R209 and R210 (phasor "c" in diagram "11"), (2) R226 (phasor "b" in diagram "11"), and, (3) R232 (phasor "a" in diagram "11"). Because of the low impedance at the emitter of Q205, the signal levels at that point are quite low. To properly view the resultant signal, one should monitor the collector of that transistor or the emitter of Q204.

At frequencies removed from the resonant frequency, the three signal currents do not null, with a resulting net input signal at the base of Q204. This signal is amplified by common emitter stage Q203, the gain of which is the ratio of R212 (the collector current of Q203 flows through this resistor) to the "net" emitter circuit resistance of Q203. As the front-panel Q Adjust Control determines the emitter circuit resistance, it effectively controls the gain of Q203. Note that the output signal of Q203 and the output signal from the Preamplifier Board are both developed across R212. Because the output of Q203 opposes the Preamplifier output, and becomes larger the further the frequency of the Preamplifier output signal is from the resonant frequency, the input signal to the Signal Tuned Amplifier (recall that the signal at the collector of Q206 was defined as the input signal) becomes smaller above and below the resonant frequency. At frequencies very far from the resonant frequency, the signal at the output of the Signal Tuned Amplifier approaches zero. To see why this is so, separately consider the circuit operation at frequencies very much lower than the resonant frequency, and at frequencies very much higher.

At very low frequencies the effect of the two phase-shift networks becomes negligible. As a result, the two signal currents mixed at the emitter of Q217 (junction of R234 and R235) will be equal in amplitude but exactly 180° out-of-phase, and the net output of the amplifier will be zero. Also, the two signals supplied to the nulling point by Q212 and Q215 will also be equal

in amplitude but opposite in phase, with the result that, in effect, only the unit phasor will be applied to the nulling point. With only the unit phasor applied, maximum cancellation of the Preamplifier output signal and the Q203 output signal takes place, and the signal at the collector of Q206 is reduced to 1/2Q of its resonant value.

At very high frequencies, the results are the same but for different reasons. The signal applied to the first phase-shift network is shorted to ground by the capacitive component of that network, and that applied to the second phase-shift network is also shorted to ground. Consequently, no signal reaches R234 or R235, and the output of the amplifier is zero. Also, the two signals supplied to the nulling point by Q212 and Q215 are zero; as before, only the unit phasor is applied to the nulling point, and the Signal Tuned Amplifier input signal is reduced to 1/2Q of its magnitude at resonance.

Note the as yet unmentioned transistors Q200 and Q201. The only function of this dual emitter follower type "regulator" is to provide a constant voltage (+5.8 V) to the Q Adjust Control Circuit.

In addition to the Signal Tuned Amplifier, several other circuits are also located on the Signal Tuned Amplifier Board. Included are an isolation stage consisting of common base amplifier Q217 and emitter follower Q218, a phase splitter consisting of transistors Q219 through Q223 and their associated components, the Overload Detect Circuit (Q224 through Q226), and finally the Signal Limiter (Q227 through Q230).

ISOLATION CIRCUIT AND PHASE SPLITTER

Observing the schematic, note that the output of the Signal Tuned Amplifier (collector of Q217) is applied to emitter follower Q218. The output of the emitter follower is applied to the input of the phase splitter at the base of Q219. Of the transistors which constitute the phase splitter, Q221 is a constant current source for the pair Q219-Q220, which amplifies the signal and provides the two 180° out-of-phase outputs. Emitter followers Q222 and Q223 furnish a low impedance drive to the following circuits (Mixer and/or Signal Limiter according to the position of the Meter/Monitor Switch). Note that the signal supplied to pin 1 of the rear panel octal socket is taken from the emitter of Q223 by way of R257.

OVERLOAD DETECT CIRCUIT

The signals at the emitters of Q222 and Q223 are also supplied to the bases of emitter followers Q224 and Q225. Diodes D200 and D201 are reverse biased (DC) by five volts. As both the emitter and base of Q226 are returned to ground, that transistor is normally cut off and the front panel Overload Light will be off. Should the Signal Tuned Amplifier be overloaded, the voltage swings at the emitters of Q224 and Q225 will be sufficient to overcome the reverse voltage across D200 and D201 and bias Q226 into conduction, lighting the Overload Lamp. The purpose of diodes D202, D203 and capacitor C214 is to act as a "Miller Integrator" and hold Q226 in conduction longer than the duration of the signal which biased it into conduction. As a result, even brief transients will light the Overload Lamp long enough to be noticeable.

SIGNAL LIMITER

The last circuit located on the Signal Tuned Amplifier Board is the Signal Limiter. Referring to the schematic, note that the input of this circuit is at the bases of Q227 and Q230. These two common emitter amplifiers drive the pair Q228-Q229, which provides the output. Trim-potentiometer R293 allows the output amplitude to be set to the proper level. Finally, diodes D204, D205, D206, and D207 prevent the transistors from being overdriven.

4.7 REFERENCE TUNED AMPLIFIER BOARD

REFERENCE TUNED AMPLIFIER

Referring to the schematic on page VIII-5, note that the Reference Tuned Amplifier proper is similar to the Signal Tuned Amplifier, the only differences being in the input circuit. Consequently, this discussion is confined to the input circuit. If the reader is not familiar with the Signal Tuned Amplifier, he is advised to refer to the description of that amplifier to gain the background essential to understanding the Reference Tuned Amplifier.

The Reference Input Signal is coupled through capacitor C304 to the base of emitter follower Q301, which in turn drives emitter follower Q302. From this transistor, the signal is applied to common base amplifier Q303. The gain of this transistor (determined by the ratio of R310 to the net emitter circuit resistance of Q303) is approximately 20 at resonance and lower at frequencies above and below the resonant frequency. In this amplifier, the three nulling currents are mixed at the emitter of Q305 with the resulting signal being developed across R312. At resonance, the three signals null exactly and the base of Q303 is "fixed", thereby achieving maximum possible gain. Above and below the resonant frequency the three signals do not null and a signal appears at the base of Q303 which opposes the signal injected at the emitter. The further the input signal is from the resonant frequency, the larger the opposing signal becomes and the lower the gain of the stage. As in the case of the Signal Tuned Amplifier, only the "unit phasor" appears at the nulling point at frequencies "far" from the resonant frequency and the gain of Q303 is reduced to one. All of the remaining Reference Tuned Amplifier circuits are the same as in the Signal Tuned Amplifier. As a final note, the Q of the Reference Tuned Amplifier is determined by the gain of Q303. As this gain is constant, so is the Q, the actual value being ten.

ISOLATION AND PHASE SHIFT CIRCUITS

Observing the schematic, note that the output of the Reference Tuned Amplifier (collector of Q316) is applied to two transistors, those being emitter follower Q317, which supplies the Reference Monitor Signal, and phase splitter Q318, which produces the 0° and 180° signals. Emitter followers Q319 and Q320 provide isolation between the phase splitter and the following circuits. The 90° output is generated from the plus and minus forty-five degree signals (phasor diagrams "9" and "10"). Observe that the -45° signal is applied directly to the emitter of Q322 and that the +45° signal is inverted by Q321. This inverted signal, which lags the 0° signal by 135°, is mixed with the -45° signal in the emitter circuit of Q322. The resultant signal, as is shown by phasor diagram "16", lags the 0° signal by 90°. Phase splitter Q323

then produces the 90° and 270° outputs and emitter followers Q324 and Q325 provide isolation.

The four outputs thus derived are applied to the Quadrant Switch. Additionally, these signals are applied to the Phase Control as shown in Figure IV-4. The arrangement used allows the signal supplied to the Mixer to be phase-shifted from 0° to 100° relative to the phase selected with the Quadrant Switch.

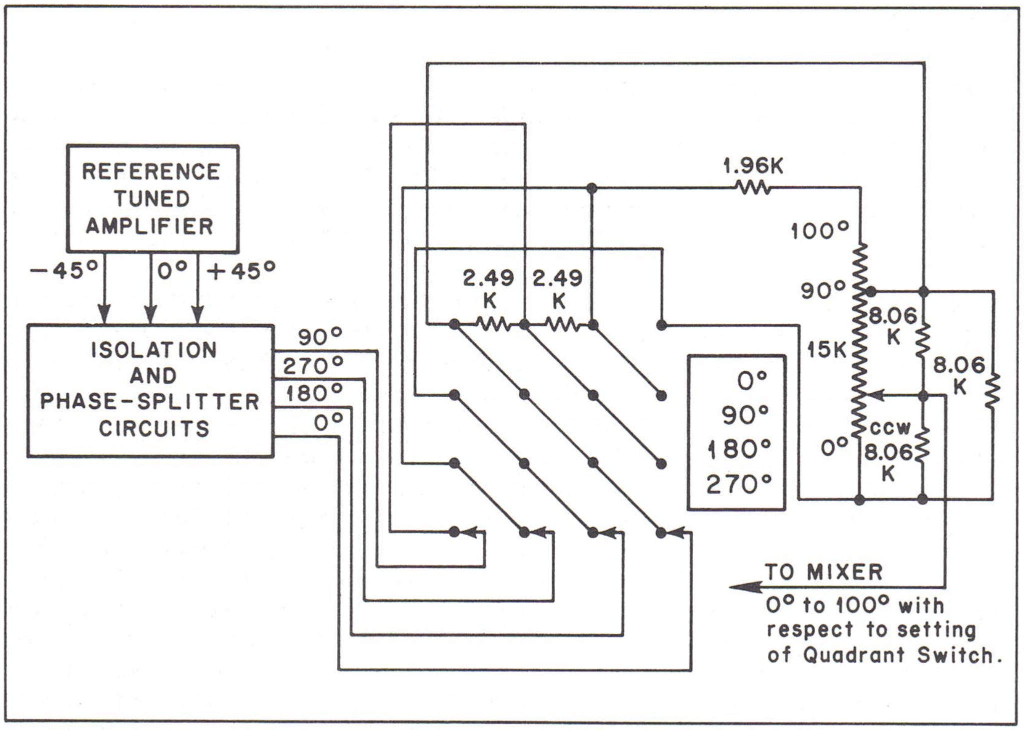


Figure IV-4. BLOCK DIAGRAM OF REFERENCE PHASE CIRCUITS

REFERENCE LIMITER

Also located on the Reference Tuned Amplifier Board is the Reference Limiter (Q326-Q327), which establishes the peak-to-peak amplitude of the calibration signal. Note that the signal at the emitter of Q317 is supplied to the limiter input (base of Q326). In the "CAL. 10 mV" and "INT." Modes, the limiter output (junction of R371 and R372) is applied to the input of the Reference Tuned Amplifier by way of the Reference Mode Switch. With the positive feedback applied, the amplifier oscillates at the tuned frequency. The "INT." and "CAL. 10 mV" modes differ only in the signal which is supplied to the Reference "IN/OUT" Jack. In the "INT." Mode, the sine-wave output of the Reference Tuned Amplifier is available at the jack, but in the "CAL. 10 mV" Mode, the 22.2 mV peak-to-peak square wave is supplied to the jack to facili-

tate gain calibration. NOTE: The rms amplitude of the fundamental component of 22.2 mV peak-to-peak square wave is 10 mV.

SOURCE FOLLOWER

The last circuit on the Reference Tuned Amplifier Board is the Reference Source Follower, which provides isolation between the Reference Amplitude Vernier and the following circuits. Refer to the Block Diagram on page VIII-2 to see how this circuit is connected in the different reference modes.

4.8 MIXER BOARD

MIXER

The phase Sensitive Demodulator or Mixer basically acts as a double-pole, double-throw switch to convert an applied input AC signal to a unidirectional current. Observing the schematic, page VIII-6, note that the Reference Drive Signal (wiper of the Phase Control in all but the "EXT." Mode, or when the Meter/Monitor Switch is set to "SIG.") is applied to the input of the Shaper at the base of Q720. This transistor in turn drives the limiter pair, Q721-Q722. The differential limiter output is applied to the pair Q723-Q724, which determines the voltage swing of the drive signal to the two switching pairs (Q701-Q702 and Q703-Q704). During a given half-cycle of the reference signal, one transistor in each pair will be conducting and the other will not. During the following half-cycle the conducting transistor cuts off and the cut-off transistor conducts. At any moment, the polarity of the signal applied to Q705 or Q706 depends on the polarity of the input signal and on the state of the switching pairs as determined by the reference signal (-12 V on a gate turns the transistor on, +6 V turns it off). The amplitude of the signal applied to Q705 or Q706, however, depends only on the amplitude of the Mixer input signal. If the reference signal is present but not the input signal, clearly there will be no signal at the base of Q705 or at the base of Q706. If the input signal is present but not the reference signal, synchronous rectification does not take place. The AC signal is simply coupled into the following amplifier and the amplified signal is applied to the panel meter and output connectors. If the selected time constant is long relative to the signal frequency, this AC signal will of course be severely attenuated.

Figure IV-5, which shows one of the Mixer outputs for in-phase and quadrature signals respectively, clearly illustrates the phase-sensitive characteristics of the Mixer. If the signal and reference inputs are either in phase or 90° out-of-phase, the signal at the base of Q706 will be as indicated in Figure IV-5. Obviously, for signals 180° out-of-phase, the mixer output will be the inverse of the in-phase output, and for signals 270° out-of-phase, the output will be the inverse of the 90° output. Taking the maximum possible area which can be enclosed by the output (one polarity) over one cycle as a unit output, the output averaged over a cycle for any mixer input phase relationship will be the unit output times the cosine of the angle between the input and reference signals.

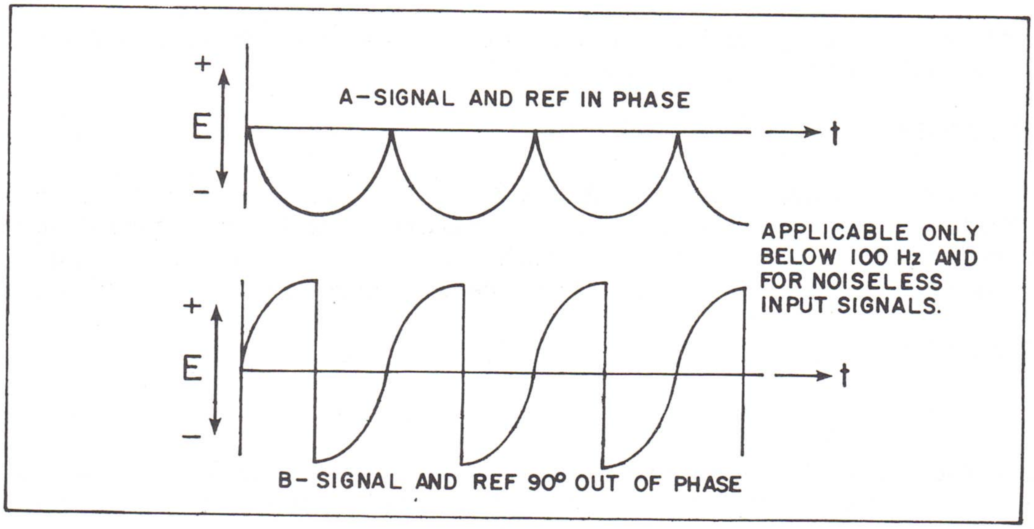


Figure IV-5. MIXER OUTPUT FOR IN-PHASE AND 90° OUT-OF-PHASE SIGNALS

The cosine response depends on the sinusoidal nature of the input signal. If the signal, for example, were a square wave, the case when the Meter/Monitor Switch is set to "PHASE", the Mixer output would vary linearly with the angle between the signal and reference inputs. As before, maximum output is obtained at 0° and 180°, while zero output is obtained at 90° and 270°.

It might be mentioned that the waveforms illustrated in Figure IV-5 apply only at frequencies below 100 Hz. At higher frequencies, the effect of the internal mixer filtering becomes evident. Also, realize that these waveforms are idealized in the sense that noiseless input signals are assumed. Even relatively low input noise can completely obscure these signals.

DC AMPLIFIER AND TIME CONSTANT

The differential mixer output is supplied to the DC Amplifier, which comprises transistors Q705 through Q713 and their associated components. This amplifier is a balanced operational amplifier with a feedback determined gain of 200, and a frequency response (6 dB per octave rolloff) as determined by the setting of the front panel Time Constant Switch. Each successively higher time constant setting results in a larger capacitance being inserted between the input and the output of the amplifier. By increasing the response time in this manner, noise accompanying the signal will be suppressed, and the output of the amplifier will be a smooth DC level proportional to the rms value of the fundamental frequency component of the input signal.

Considering the function of the individual amplifier stages, Q707 is a constant current source for the input pair, Q705-Q706. Emitter followers Q708 and Q709 provide isolation between this pair and the second amplifying pair, Q710-Q711, which provide the outputs. Both outputs (collectors of Q710 and Q711) are sampled by Q712 through R726 and R728. The algebraic sum of the two outputs (common mode output level) is maintained at zero volts by the differential amplifier Q712-Q713, which controls the current supplied to the

input pair by Q707. The current supplied by Q707 is automatically varied so as to keep the potential at the base of Q712 (algebraic sum of the two outputs) the same as that at the base of Q713 (within a few millivolts of ground).

Because the amplifier is a true differential input, differential output, balanced amplifier, there are two separate but identical feedback paths, the first through R715 and the second through R716. In as much as only the output fed back through R715 is used, the gain is simply the ratio of R715 to the net source impedance, or approximately 200. When the input to the Mixer is 50 mV rms (single-ended), the DC output is 10 V.

Note that the front panel Zero Suppress Control allows a variable offset to be inserted at one of the amplifier inputs. The range of the control is a calibrated ±10 times full scale.

OUTPUT AMPLIFIER

The output of the DC Amplifier is applied to the input of the Output Amplifier, a simple gain-of-one operational amplifier, which, besides allowing the additional low-pass filtering required to obtain the 12 dB per octave rolloff, drives the output connectors and the panel meter. Observing the schematic, note that the amplifier comprises transistors Q714 through Q719, along with their associated components. Considering their function separately, Q716 is a constant current source for the input pair, Q714-Q715. Pair Q717-Q718 provides additional gain, and emitter follower Q719 provides isolation between the final pair and the various outputs. The gain is one, as determined by the ratio of R734 to R733. When the front-panel 6 dB/12 dB Switch is set to "12 dB", a capacitor appropriate to the selected time constant is switched in parallel with R734 to achieve the "fast" rolloff.

4.9 POWER SUPPLIES

The AC and Unregulated DC Supplies are illustrated on the Chassis Wiring Diagram, page VIII-8. Referring to this diagram, note that either 115 V or 230 V, 50-60 Hz, is routed through the line fuse. Power Switch, and Line Voltage Selector Switch to the split primary windings of the power transformer. For 115 V operation, the two primary windings are in parallel. For 230 V operation, they are in series. The secondary output is applied across a rectifier bridge to obtain unregulated plus and minus thirty-three volts. This unregulated DC is supplied to the regulators located on the Power Supply Board (schematic on page VIII-7). There are two regulators. The first receives -33 V from the rectifiers and regulates it to -24.0 V. Zener diode D505 provides the reference and trim-potentiometer R510 allows the output level to be accurately set. The second regulator accepts the +33 V output of the rectifiers and regulates it to +24.0 V. Note that the reference for this regulator is the -24.0 V regulated output of the first circuit, and that the output level of the +24.0 V regulator is determined by the setting of R533.

Three fuses protect the instrument circuitry. Two of these are 3/8 ampere fast-blo fuses in the plus and minus unregulated thirty-three volt lines. The third is a 1/4 ampere slo-blo fuse in the AC line before the Power Switch.

4.10 FREQUENCY DOUBLER

When the instrument is operating in the "EXT. f/2" Mode, the Reference Signal is routed to the Frequency Doubler (schematic on page VIII-7) prior to being applied to the reference input of the Mixer. Consider the operation of the frequency Doubler over one input cycle of a sine wave, beginning with the negative half cycle. Source follower Q513 supplies the negative half cycle at a low impedance to Q514, which acts as a simple common-emitter, gain-of-one amplifier. The inverted "negative half cycle" appears as a positive half cycle at the collector of Q514. When the input waveform goes positive, Q514 saturates, and source follower Q513 drives the output directly. Consequently, for both halves of the input waveform, the output waveform is the same, a positive going "half-sinewave". The output is similar to that of a loaded but unfiltered full-wave rectifier. This "frequency doubled" signal is then routed to the Reference Tuned Amplifier, which, when operating in this mode, must be tuned to twice the frequency of the signal being applied to the Reference "IN/OUT" Jack.

SECTION V
ALIGNMENT PROCEDURE

5.1 INTRODUCTION

The Model 121 is a reliable instrument, and as such, will give long trouble-free service. However, as an assurance that no component aging effects are taking place which might gradually degrade instrument performance, the following alignment procedure should be carried out every two years.

Because some of the adjustments interact, the entire alignment should be performed in sequence. Any decision to make only a partial alignment should be reserved to someone having sufficient knowledge of the instrument to determine where interaction is a problem and where it is not. The location of the circuit boards is indicated in Figure V-1. Separate circuit board diagrams, which show the location of the components and adjustments, are provided. The diagram for each board is located on the same page as the corresponding schematic (see page VIII-1).

If any problems are encountered in performing the alignment, the operator is referred to the following section on troubleshooting. Should any assistance or advice be required, contact the factory or one of PAR's authorized representatives, a list of whom appears at the end of the manual.

5.2 EQUIPMENT NEEDED

(1) Extender Board, PAR # EB 1159-3. This board can be obtained from PAR.

(2) Oscilloscope, sensitivity of 5 mV/cm or better, rise time of 50 ns, calibrator square wave output, external trigger. Suggested instrument--Tektronix type 543B with a type H or type L plug-in.

(3) Oscillator, frequency range 5 Hz to 150 kHz, output 5 V rms into 600 ohms. Suggested instrument--HP type 200 CD.

(4) Voltmeter, 0.5% accurate at 24 V, input impedance 1 megohm or higher, capable of indicating zero volts plus or minus 10 mV. Suggested instrument--NLS type X2.

(5) Attenuator, Input impedance 10 kilohms or higher, attenuation steps 1/2, 1/5, 1/10, 1/20, 1/50, 1/100, and 1/200. Accuracy ±0.5%.

(6) 10 megohm, 10:1 attenuator probe for the oscilloscope.

(7) Cables to interconnect the Model 121 and the test instruments.

(8) Alignment screwdriver.

5.3 PRELIMINARY STEPS

(1) Remove the top and bottom covers.

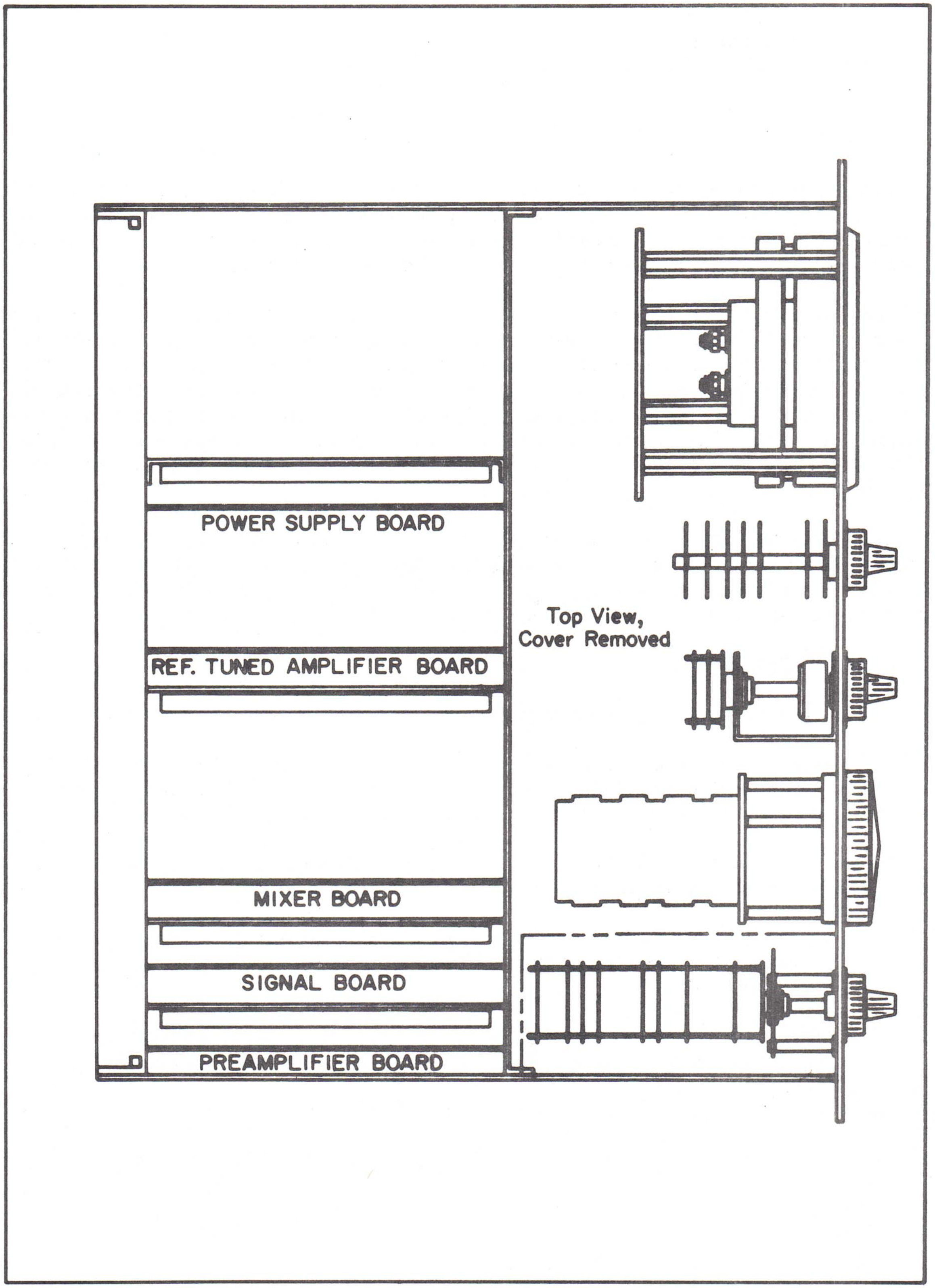


Figure V-1. LOCATION OF CIRCUIT BOARDS

(2) Remove all the plug-in circuit boards, plug the Power Supply Board into the Extender Board, and insert the Extender Board (Power Supply Board attached) into the Power Supply Board socket. Turn the power on.

(3) Set the mechanical zero on the panel meter.

(4) Check the two bulbs which illuminate the panel meter. If they are discolored or burned out, replace them with GE type 1819 bulbs. NOTE: Although the bulbs can be removed and replaced without removing the metal strip which runs along the front upper edge of the instrument, it is much easier to "get at" the bulbs with the strip removed. Consequently, it is generally advisable to remove the strip, which simply "lifts off" once the four corner screws have been removed.

5.4 POWER SUPPLY BOARD (see Figure V-1 for board location)

REGULATOR ADJUSTMENTS

(1) Measure the voltage between pin 8 and pin 5 (ground) of the Power Supply Board. The measured voltage should be within 3/10 of a volt of -24.0 V. If it is not, adjust R510 to obtain an indicated voltage of -24.0 V.

(2) Remove the voltmeter from pin 8 and connect it to pin 9. The measured voltage should be within 3/10 of a volt of +24.0 V. If it is not, adjust R533 to obtain an indicated voltage of +24.0 V. Remove the voltmeter.

FREQUENCY DOUBLER

(1) Set the Mode Switch to "EXT. f/2". Apply a 400 kHz sinewave at 1.5 V rms to the Reference "IN/OUT" Jack. Observe the signal at pin 19 with the oscilloscope. The signal should be as indicated in Figure V-2. If the peaks are unsymmetrical, adjust R535 as necessary to obtain proper symmetry.

UPPER TRACE
Output Signal (800 Hz)
Horizontal = .5 ms/cm
Vertical = .2 V/cm

LOWER TRACE
Input signal (400 Hz)
Horizontal = .5 ms/cm
Vertical = 2 V/cm

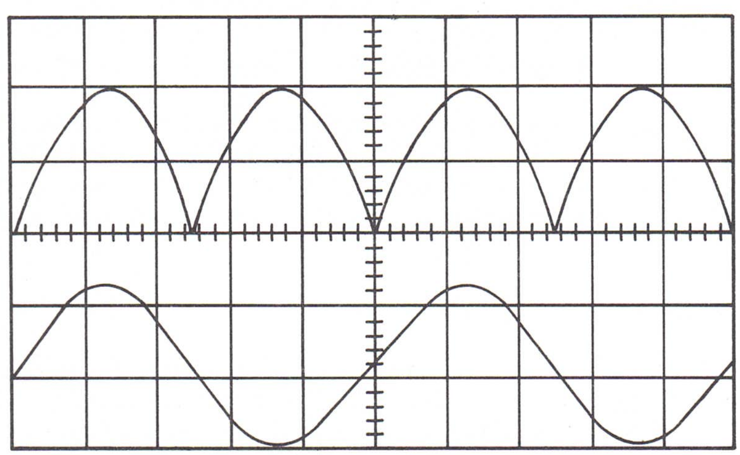


Figure V-2. OUTPUT OF FREQUENCY DOUBLER WITH SINE WAVE INPUT

(2) Remove the oscilloscope and turn the power off. Then separate the Extender Board and the Power Supply Board, remove the Extender Board, and return the Power Supply Board to its socket.

5.5 REFERENCE TUNED AMPLIFIER BOARD

REFERENCE ATTENUATOR

(1) Set the front-panel controls as follows.

Mode Switch ------------------------- SEL. EXT.
Reference Attenuator Switch --------- 1.0
Reference Attenuator Vernier -------- fully clockwise

(2) Apply a 1 V rms sine wave at 400 Hz to the Reference "IN/OUT" Jack. Monitor pin 20 of the Reference Tuned Amplifier socket with the oscilloscope. The observed signal should be identical to the input signal. Begin rotating the Reference Attenuator Switch counter-clockwise. Observe that the amplitude of the monitored signal decreases as indicated by the switch setting. The signal should disappear altogether in the "OFF" position. Return the switch to the fully clockwise position. Rotate the Reference Vernier Control fully counter-clockwise. The amplitude of the monitored signal should decrease, tracking the control setting, and should reach a minimum value of 2/5 of the original amplitude when the control is fully counter-clockwise.

LOW FREQUENCY REJECTION

(1) Plug the Reference Tuned Amplifier Board into the Extender Board and insert the Extender Board (Reference Tuned Amplifier Board attached) into the Reference Tuned Amplifier Board socket. Turn the power on.

(2) Disconnect the oscilloscope from pin 20 and connect it instead to pin 15. After setting the front-panel Frequency Multiplier to "$X10^2$" and the Main Tuning Dial to "4", carefully adjust the Main Tuning Dial for maximum signal amplitude as observed at pin 15. Change the setting of the Reference Attenuator Switch and Vernier as necessary to achieve a peak-to-peak amplitude of 5 V.

(3) Reduce the frequency of the applied signal from 400 Hz to 40 Hz. Then set the Model 121 Frequency Multiplier Switch to "$X10^4$". Adjust trim-potentiometer R322 for minimum 40 Hz signal at pin 15. The observed signal after completing the adjustment should be less than 5 mV peak-to-peak.

NULL ADJUST

(1) Increase the frequency of the applied signal from 40 Hz to 400 Hz. Then set the Model 121 Frequency Multiplier Switch to "$X10^2$" and adjust the Main Tuning Dial for a maximum at pin 15.

(2) Remove the oscilloscope from pin 15 and connect it to that end of R311 which is furthest from the upper edge of the board. Adjust trim-potentiometer R314 for an observed null. After completing the adjustment, the amplitude of the signal at R311 should be less than 10 mV peak-to-peak. Remove the signal generator.

SOURCE FOLLOWER ZERO

(1) Monitor pin 4 with the voltmeter.

(2) Adjust R378 for an indicated voltage of zero.

(3) Remove the voltmeter.

REFERENCE LIMITER ADJUSTMENTS

There is one limiter adjustment, R376, which sets the amplitude of the calibration output. In general, this adjustment ought not to be disturbed unless a component failure in the circuit has occured. If the circuit has failed and been repaired, R376 is adjusted for a calibrate output amplitude of 22.2 mV ptp (±0.5%). Because this adjustment affects the amplitude of the calibrate signal, it should not be touched unless one has means of measuring the calibrate signal to the specified accuracy. This measurement can be direct (meter) or indirect (comparison with a known accurate signal).

AMPLIFIER CHECK

(1) Set the Mode Switch to "INT." Then, using the oscilloscope, successively monitor the signal at pins 11, 12, 13, 14, and 15. The signal observed at each pin should be approximately 1 V rms at 400 Hz and the amplitude deviation from pin to pin should be no more than ±3%.

(2) Leaving the oscilloscope on pin 15, tune the instrument over its entire frequency range. The amplitude of the observed signal should stay within 10% of its initial value. At 150 kHz it might be necessary to adjust trim-capacitor C315 to bring the signal amplitude within tolerance. NOTE: Be sure the oscilloscope probe is properly compensated before assuming that C315 needs adjustment.

(3) Remove the oscilloscope and turn the power off. Then separate the Extender Board and the Reference Tuned Amplifier Board, remove the Extender Board, and return the Reference Tuned Amplifier Board to its socket.

5.6 PREAMPLIFIER BOARD

COARSE GAIN CHECK

(1) Plug in the Preamplifier Board directly (without the Extender Board). Then turn the power on.

(2) Check that the voltage at pin 5 is +15 V (±0.5 V) and that the voltage at pin 4 is -15 V (±0.5 V).

(3) Connect a cable from the Reference "IN/OUT" Jack to the "SIG. IN" Jack. The Mode Switch should still be set to "INT."

(4) Using the oscilloscope, measure the gain from the "SIG. IN" Jack to pin 10 of the Preamplifier Board. Change the setting of the Reference Attenuator Switch and Vernier as necessary to keep the observed signals at a convenient level. Take care not to overload the Preamplifier, as would be evidenced by distortion of the signal observed at pin 10. The gain (for each position of the Sensitivity Switch should approximately be as indicated in Table V-1.

Sensitivity Switch Setting	Gain
500 mV	1/50
200 mV	1/20
100 mV	1/10
50 mV	1/5
20 mV	1/2
10 mV	1
5 mV	2
2 mV	5
1 mV	10
500 μV	20
200 μV	50
100 μV	100
50 μV	200
20 μV	500
10 μV	1000

TABLE V-1. PREAMPLIFIER GAIN

(5) Disconnect the cable interconnecting the Reference "IN/OUT" and "SIG. IN" Jacks. Then turn the power off and remove the oscilloscope.

5.7 MIXER AND DC AMPLIFIERS

SYMMETRY CHECKS

(1) Set the front-panel controls as follows.

Meter/Monitor Switch	OFF
Reference Attenuator Switch	1.0
Reference Attenuator Vernier	fully clockwise
Time Constant	OFF and 6 dB
Frequency Multiplier Switch	$X10^2$
Main Tuning Dial	4.0
Mode Switch	INT.

(2) Plug the Mixer Board into the Extender Board and insert the Extender Board (Mixer Board attached) into the Mixer Board Socket. Turn the power on.

(3) Trigger the oscilloscope from the Reference "IN/OUT" Jack. Then, with the oscilloscope DC coupled and using the probe, monitor the signal at the end of R765 which is furthest from the edge of the board. The observed signal should be a square wave at the tuned frequency. It should swing from +6 V to -12.5 V, and the duty factor should be 50% (±1%).

(4) Set the Mode Switch to "EXT." Then apply a 3 V peak-to-peak sine wave at 150 kHz to the Reference "IN/OUT" Jack. Observe that the symmetry and rise time of the monitored signal are as indicated in Figure V-3.

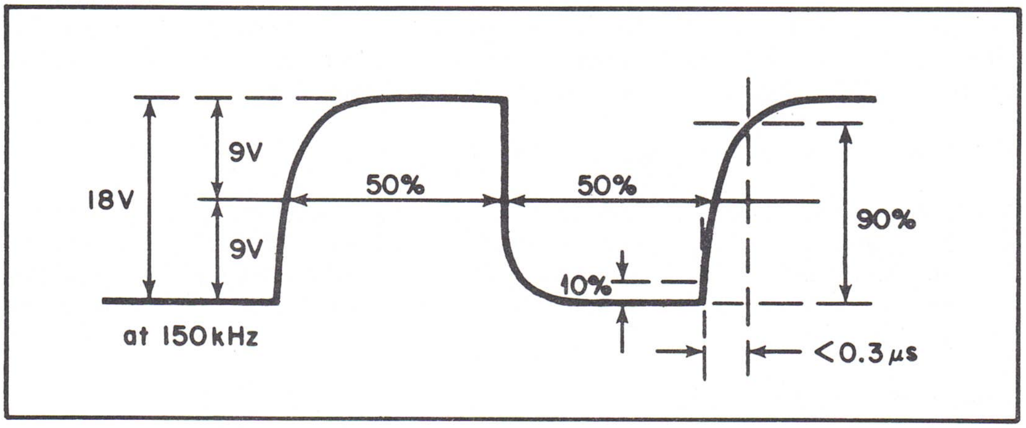


Figure V-3. HIGH FREQUENCY SYMMETRY

(5) Remove the oscilloscope and signal generator.

ZERO ADJUSTMENT

(1) Set the front-panel controls as follows.

Zero Suppress Switch ------------------	center position
Mode Switch ---------------------------	INT.
Frequency Multiplier ------------------	X10^2
Main Tuning Dial ----------------------	4.0
Meter/Monitor Switch ------------------	OUT X10
Time Constant -------------------------	300 ms and 6 dB

(2) Connect pins 19 and 20 of the Mixer Board together with a short jumper.

(3) Connect the voltmeter between pin 14 (ground) and the collector of Q711. Adjust trim-potentiometer R710 for a meter indication of 0 V (±10 mV). If the 0 V indication can not be obtained, see "DC BALANCE", which follows. If the adjustment can be made, proceed to

step 4.

(4) Remove the voltmeter from the collector of Q711 and connect it instead to pin 17. Adjust trim-potentiometer R742 for a meter indication of 0 V (±10 mV).

(5) Remove the voltmeter but leave the jumper between pins 19 and 20 in place.

DC BALANCE

This adjustment is not ordinarily necessary. It should be carried out only if step 3 of the Zero Adjustment could not be made. To verify that the DC Balance Adjustment is necessary, remove the jumper from pins 19 and 20 and connect it instead from Test Point 1 to the end of R703 which connects to the source of Q701 and of Q703. If it is still impossible to obtain 0 V at the collector of Q711 by adjusting R710, reconnect the jumper across pins 19 and 20 and proceed as follows. If proper adjustment of R710 is possible with R703 and the test point shorted together, one of the Mixer switching transistors, Q701 through Q704, is probably defective.

(1) Set R710 to the center of its range.

(2) While continuing to monitor the voltage between the collector of Q711 and ground, adjust trim-potentiometer R717 for a meter indication as near zero as can be obtained. Then adjust R710 as required to obtain a meter indication within 10 mV of zero. Proceed to step 4 above.

ZERO SUPPRESS CALIBRATION

(1) Set the Meter/Monitor Switch to "OUT" and the Zero Suppress Switch to "+".

(2) Set the Zero Suppress Dial to "1.0", that is, exactly one full turn from the fully counter-clockwise setting.

(3) Adjust trim-potentiometer R707 for a panel meter indication of exactly +100%.

(4) Set the Zero Suppress Switch to "-". The panel meter should indicate -100% (±3%).

(5) Turn the power off. Then separate the Extender Board and the Mixer Board, remove the Extender Board, and return the Mixer Board to its socket (maintain the jumper between pins 19 and 20. For convenience sake, it is easiest to jumper the socket pins beneath the board). Turn the power back on.

(6) Connect the voltmeter to the Monitor Jack. Note the indicated voltage. Then set the Frequency Multiplier Switch to "$X10^4$" and the Main Tuning Dial to "15.0". The indication should have changed less than 20 mV.

(7) Disconnect the voltmeter and remove the jumper. Turn off the power and set the Zero Suppress Switch to the center position.

5.8 SIGNAL TUNED AMPLIFIER BOARD

LOW FREQUENCY REJECTION

(1) Remove the Mixer Board and plug in the Signal Tuned Amplifier Board (using the Extender Board). Turn the power on.

(2) Set the Sensitivity Switch to "10 mV" and connect an external sine wave to the "SIG. IN" Jack. The amplitude of the sine wave should be approximately 0.4 V peak-to-peak and the frequency should be 400 Hz.

(3) Set the Frequency Multiplier Switch to "$X10^2$" and the Main Tuning Dial to "4.0".

(4) Monitor pin 12 of the Signal Tuned Amplifier with the oscilloscope and adjust the Main Tuning Dial for maximum observed signal.

(5) Vary the amplitide of the input signal as necessary to establish the amplitude of the observed signal at 5 V peak-to-peak.

(6) Decrease the frequency of the applied signal to 40 Hz and set the Frequency Multiplier Switch to "$X10^4$".

(7) Adjust trim-potentiometer R223 for minimum observed 40 Hz signal. It should be possible to reduce the 40 Hz signal to less than 5 mV peak-to-peak. Remove the oscilloscope.

NULL ADJUST

(1) Increase the frequency of the applied signal to 400 Hz and set the Frequency Multiplier Switch to "$X10^2$".

(2) Monitor the emitter of Q204 with the oscilloscope. Adjust the Main Tuning Dial and the Frequency Trim Control for an observed null. Then adjust R210 for an observed null. After completing the adjustment, the amplitude of the observed signal should be less than 10 mV.

(3) Remove ths oscilloscope from the emitter of Q204 and connect it instead to pin 12. Vary the front-panel Q Control over its entire range. If any change is noted in the amplitude of the observed signal, re-adjust R210 as necessary to prevent amplitude changes as the Q Control is varied.

OVERLOAD CHECK

(1) While continuing to monitor the signal at pin 12, gradually increase the amplitude of the input signal. The front-panel Overload Light should come on when the amplitude of the observed signal is in the range of 13.0 to 13.5 V peak-to-peak. When the amplitude of the sig-

nal is in the range of 14.0 to 14.5 V peak-to-peak, amplifier limiting will take place. Finally, adjust the amplitude of the input signal for an observed output level of exactly 5 V peak-to-peak. Note and record the input signal level.

HIGH FREQUENCY RESPONSE

(1) Increase the frequency of the input signal to 150 kHz, taking care to be sure that its amplitude is exactly the same as recorded above. Tune the Model 121 to 150 kHz. Then fine-tune for maximum observed signal at pin 12. Adjust C204 as necessary to establish the amplitude of the signal at pin 12 at exactly 5 V peak-to-peak. Remove the oscilloscope and signal generator. Turn the power off and return the Mixer Board to its socket. Then turn the power back on.

SIGNAL LIMITER ADJUSTMENTS

(1) Set the front-panel controls as follows.

Meter/Monitor Switch -------------------- PHASE
Mode Switch ----------------------------- CAL. 10 mV
Frequency Multiplier -------------------- $X10^2$
Main Tuning Dial ------------------------ 4.0
Both Phase Controls --------------------- 0°
Sensitivity Switch ---------------------- 1 mV

(2) Connect a cable from the Reference "IN/OUT" Jack to the "SIG. IN" Jack.

(3) Adjust the Frequency Trim Control for maximum meter indication. Then adjust trim-potentiometer R293 for a meter indication of 90% (±0.5%).

(4) Vary the Sensitivity Switch over the range of "100 μV" to "10 mV". The panel meter indication should change less than 2%.

(5) Set the Frequency Multiplier Switch to "$X10^4$" and the Main Tuning Dial to "15.0".

(6) Adjust the Frequency Trim Control for maximum meter indication. Then vary the Senstivity Switch over the range of "100 μV" to "10 mV". The meter indication should stay within the range of 85% to 90% of full scale. Leave the Sensitivity Switch set to "10 mV". Then, after turning the power off, remove the Signal Tuned Amplifier Record from the Extender Board and return the Signal Tuned Amplifier Board to its socket. Turn the power on.

5.9 FRONT PANEL CONTROLS

Q CONTROL

(1) Set the front-panel controls as follows.

Frequency Multiplier Switch ---------- $X10^2$

Main Tuning Dial -------------------- 4.0
Meter/Monitor Switch ---------------- SIG.
Q Control --------------------------- 5

(2) Adjust the Frequency Trim Control for maximum panel meter indication.

(3) Set the front-panel "ADJ." Control for a meter indication of exactly 100% of full scale.

(4) Adjust the Frequency Trim Control for a meter indication of exactly 90% of full scale.

(5) Increase the Q setting from 5 to 25. As the Q setting is increased, the panel meter indication will decrease. The final indication should be in the range of 35% to 45% of full scale.

TIME CONSTANT SWITCH

(1) Set the Frequency Multiplier Switch to "X10". Then set the Meter/ Monitor Switch to "OUT".

(2) Adjust the Frequency Trim Control for maximum meter indication.

(3) Observe the signal at the Monitor Jack with the oscilloscope. Adjust the Time Constant Switch over its entire range and verify that filtering increases with the increased time constant. For time constants above 1 second, set the Frequency Multiplier to "X1". Verify that more filtering is obtained with the Rolloff Rate Switch set to "12 dB" than is obtained with it set to "6 dB". Set the Time Constant Switch to "EXT." and verify that external capacitors connected to the proper pins of the rear panel eleven-pin socket control the time constant as indicated in Section III. Remove the external time constant capacitors and leave the Time Constant Switch set to "1 mS".

5.10 DC AMPLIFIER LIMITING

(1) While continuing to observe the signal at the Monitor Jack, set the Sensitivity Switch to "5 mV". Observe that the monitored signal clips at +16 V.

(2) Set the Phase Quadrant Selector to "180°". The observed signal should now clip at -16 V. Disconnect the cable interconnecting the Reference "IN/OUT" Jack and the "SIG. IN" Jack.

5.11 GAIN CALIBRATION

ATTENUATION FACTOR

(1) Set the Sensitivity Switch to "5 mV" and apply a 1 V peak-to-peak square wave at 1 kHz (Calibrate Output of the oscilloscope) to the "SIG. IN" Jack. Monitor pin 20 of the Preamplifier Board with the oscilloscope and carefully note the amplitude of the observed signal (approximately 0.95 of the applied signal).

(2) Rotate the Sensitivity Switch counter-clockwise from the "5 mV" position. Note that no change in the amplitude of the observed signal takes place over the entire range of "5 mV" to "10 μV".

(3) Sequentially set the Sensitivity Switch to "10 mV", "20 mV", and "50 mV". In each of these positions the amplitude of the observed signal should be 1/10 that noted in step 1.

(4) Sequentially set the Sensitivity Switch to "100 mV", "200 mV", and "500 mV". In each of these positions the amplitude of the observed signal should be 1/100 that noted in step 1. Remove the external signal and the oscilloscope. Turn the power off.

2-5-10 CALIBRATION

(1) Set the front-panel controls as follows.

Sensitivity ----------------------------	5 mV
Frequency Multiplier Switch ------------	$X10^2$
Main Tuning Dial -----------------------	4.0
Mode Switch ----------------------------	CAL. 10 mV
Both Phase Controls --------------------	0°
Q Control ------------------------------	10
Meter/Monitor Switch -------------------	SIG.

(2) Plug the Preamplifier Board into the Extender Board and insert the Extender Board (Preamplifier Board attached) into the Preamplifier Board Socket. Turn the power on.

(3) Check that the panel meter indication is exactly at zero, that is, that there is no offset.

(4) Connect the signal at the Reference "IN/OUT" Jack to the input of the precision external attenuator (set for an attenuation of 1/2). Connect the output of the attenuator to the "SIG. IN" Jack.

(5) Adjust the Frequency Trim Control for maximum meter indication. Then set the Meter/Monitor Switch to "OUT" and adjust the Phase Control for maximum meter indication.

(6) Set the "ADJ." Control for a meter indication of exactly +100%.

(7) Set the Sensitivity Switch to 2 mV and the external attenuator to 1/5. The meter indication should be +100% (±2%).

(8) Set the Sensitivity Switch to "1 mV" and the external attenuator to 1/10. The meter indication should be +100% (±2%).

CALIBRATION OF A2 AND A3

(1) Set the Sensitivity Switch to "100 μV" and the external attenuator to 1/100. Then adjust trim-potentiometer R123 (Preamplifier Board) for a panel-meter indication of exactly +100%.

(2) Set the Sensitivity Switch to "50 μV" and the external attenuator to 1/200. Then adjust trim-potentiometer R136 (Preamplifier Board) for a panel-meter indication of exactly +100%. NOTE: In checking the gain with the Sensitivity Switch set to "50 μV", it is generally advisable to check for ground loop currents. To do so, simply disconnect, at the Model 121 end only, the cable which extends from the attenuator to the "SIG. IN" Jack, and short the "SIG. IN" Jack with a BNC shorting cap. Then touch the outer conductor of the cable connector to the shorting cap. Any output indication which occurs is a result of ground loop current. If any such meter deflection is noted, simply adjust the Zero Suppress Dial for zero output, thereby nulling out the error. Then reconnect the cable properly and make the gain check and adjustment.

(3) Turn the power off. Then separate the Extender Board and Preamplifier Board and return the Preamplifier Board to its socket. Turn the power back on.

OUT X10

(1) Set the Sensitivity Switch to "10 mV" and the external attenuator to 1/10.

(2) Set the Meter/Monitor Switch to "OUT X10" and observe the panel-meter. It should indicate +100% (±2%).

REFERENCE

(1) Set the Meter/Monitor Switch to "REF."

(2) Observe the panel meter. The indication should be +50% (±5%). If this reading is off, readjust R314 (Reference Tuned Amplifier) to get the proper reading. Remove the external attenuator and connect the Reference "IN/OUT" Jack directly to the "SIG. IN" Jack (Sensitivity Switch set to "10 mV").

5.12 PHASE CHECKS

(1) Set the Meter/Monitor Switch to "PHASE" and adjust the Frequency Trim Control for maximum indication.

(2) Successively set the Phase to the values listed in Table V-2 (next page). Check that the resulting meter indications fall within the specified tolerance range.

5.13 FINAL STEPS

(1) Turn off the power and unplug the line cord.

(2) Replace the top and bottom covers.

PHASE QUADRANT SWITCH	PHASE DIAL	METER INDICATION RANGE
0	0	+80 to +95
0	45	+35 to +55
0	90	-10 to +10
90	90	-80 to -95
180	90	-10 to +10
270	90	+80 to +95

Table V-2. PHASE-CHECK SETTINGS AND TOLERANCES

SECTION VI
TROUBLESHOOTING

6.1 INTRODUCTION

Although the Model 121 is a highly reliable instrument, component deterioration or failure could cause the instrument to eventually no longer meet specifications, or even to become inoperative. Should this occur, a partial or complete alignment (Section V) will generally restore proper operation. In those cases where the malfunction is a result of component failure, aligning the instrument will of course prove to be impossible. For this reason, the following pages are provided. By following the outlined procedures, a person familiar with the operation of the Model 121 should have little difficulty in isolating the problem to a specific board. This procedure presupposes that the controls and wiring are not defective. Consequently, it is possible that a board indicated as being bad is in fact good, and that the problem is in the wiring or an associated control. After following this procedure to where a specific board is identified as being "bad", a person versed in the functioning of the instrument (Section IV) should be able to check the inputs and outputs of the board with an oscilloscope, and thereby easily determine whether or not a control or wiring problem exists.

Once the problem is isolated, the user should contact PAR for advice on the relative merits of repairing the board himself or returning it to PAR for repair or replacement. In any case, if the instrument is still in Warranty (Section VII), it is particularly important that PAR be contacted prior to attempting a field repair, as failure to do so could invalidate the Warranty.

The information provided in this section of the manual is not oriented toward making a field repair, but only toward identifying a malfunctioning circuit board. However, information provided in other sections is useful in further troubleshooting. Section IV contains detailed descriptions of the functioning of each circuit. Voltage and waveform information is furnished on the schematics at critical points. Beside each schematic is a separate components location diagram which shows the physical location of all the components mounted on the corresponding circuit board. Other useful drawings include the Circuit Board Location Diagram on page V-2, the Block Diagram on page VIII-2, and the Chassis Wiring Schematic on page VIII-8. Attention is called to paragraph 6.2 of this Section, which deals with soldering on printed circuit boards. A few minutes study of paragraph 6.2 could prove of value to those, who, although experienced in conventional soldering techniques, have not worked with printed circuit boards. Finally, realize that to signal-trace on a specific board requires that the board be mounted on an extender board, # EB 1159-3, which can be purchased from PAR.

6.2 PRINTED CIRCUIT SOLDERING

If any components are removed from the printed circuit boards for inspection or replacement, be especially careful not to damage the print. To remove components "cleanly" requires considerable care. The recommended method is "wicking." The following procedure is suitable for removing components from single sided boards (boards having print on one side only).

(1) Dip a few inches length of stranded wire (shielding braid is ideal) into some rosin base soldering flux, and then place the wire on top of the joint to be unsoldered, allowing some of the flux to flow over the joint. NOTE: Under no circumstances use an acid base flux.

(2) As shown in Figure VII-1, place a hot soldering iron (no larger than 40 watts) on top of the stranded wire directly above the joint to be unsoldered. Within a few seconds, most of the solder in the joint will flow quickly up the "wick", leaving the joint area free of solder.

(3) Lift the soldering iron and remove the "wick" before it freezes to the joint. Cut off the "filled" end of the wick (generally about 1/2 inch should be removed).

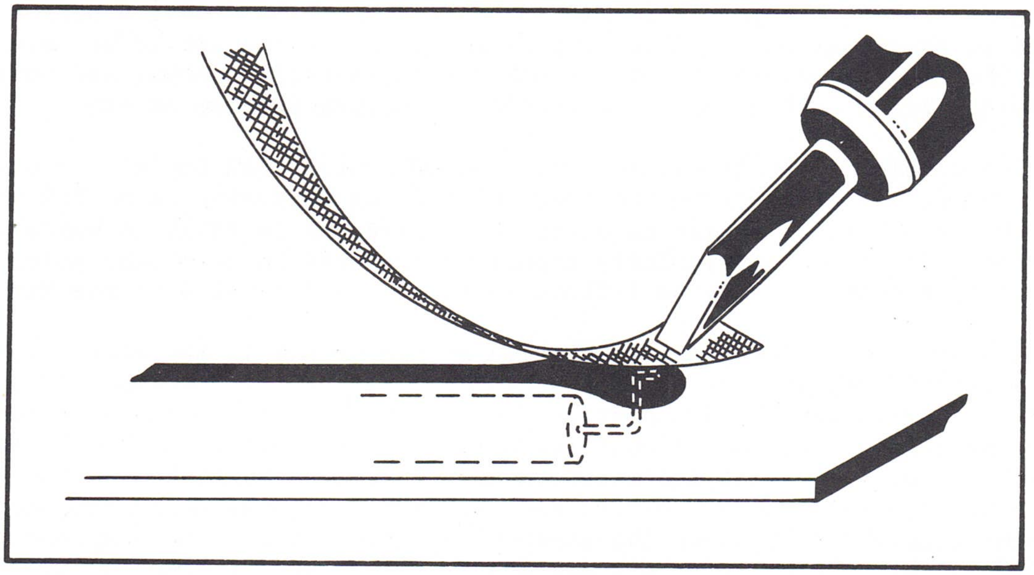


Figure VI-1. SOLDER REMOVAL BY WICKING

(4) Inspect the joint. If any solder remains, repeat steps "(1)" through "(3)" to remove any remaining solder. It should then be very easy to straighten the component lead so that the component can be removed after repeating the procedure with the other lead(s).

In returning the component or its replacement to the board, make sure that the leads are bent on the proper centers, and that they don't "angle in" or "angle out". If they do not pass freely through the centers of the holes, they may catch the edge of the print and lift it. Cut off the excess lead length and bend the leads over. Solder them with a hot iron (NO LARGER THAN 40 WATTS), using a good grade of rosin core 60/40 solder. Be sure to apply heat no longer than necessary to achieve a good joint (usually a few seconds

with a properly tinned hot iron). After soldering, clean the board with flux remover (Alpha 653 or equivalent). NOTE: No harm will result from leaving the flux on the board other than to degrade the appearance of the board.

Most of the Model 100 and Model 101 printed circuit boards are two sided boards (boards having print on both sides). Many of the mounting holes on these two sided boards are plated-through holes, which usually fill with solder when the components are mounted. As a result, somewhat different techniques must be utilized in removing and replacing components. A suitable procedure follows.

(1) Proceed as in the case of "normal" holes up to where wicking is completed and the leads straightened.

(2) Grasp the lead to be removed with long nose pliers on the component side of the board (the board should be clamped in place). Touch the soldering iron tip to the straightened lead while pulling (gently) the component away from the board with the pliers. When the solder in the holes flows (usually in a few seconds), the component can be pulled from the board at that end. Repeat for the other end and remove the component.

(3) Removing transistors and trim-potentiometers pose special problems because these components will not move with just one lead "freed". To remove such components, one must move the soldering iron tip from one lead to the next while pulling gently directly away from the board. By applying the iron to each lead for a second or two and then advancing to the next lead, all should become evenly heated, and the solder will flow in all holes at about the same time, allowing the component to be easily pulled straight away from the board.

As removing components from plated-through holes is a special problem, so is replacing components, because the holes must first be cleared of the solder which fills them. The most satisfactory technique is to melt the solder by touching the soldering iron tip to the "pad" for a few seconds, followed by quickly rapping the board, once, against the bench. The solder will fly out, leaving a clear hole. In applying this technique, it is important to move quickly, because the solder will usually freeze within a second or two after removing the iron. Do not attempt to extend the time the solder is molten by applying heat longer than necessary as this may cause the print to become detached from the board. Also, there is no point in making more than one tap per heating. By the time the second tap is made, the solder will have frozen. After clearing the solder from the holes, inspect the board closely to be sure, very sure, that no solder has splashed onto the board and shorted out adjacent ribbons. If such a solder splash is noted, remove it by wicking.

Using these techniques, no damage to the board or print will take place, and after completion of the job, the board should be indistinguishable from one which is "fresh from the factory".

6.3 EQUIPMENT NEEDED

(1) General purpose oscilloscope, such as the Tektronix type 543B with a type H or L plug-in.

(2) Sine-wave oscillator, able to produce 1 kHz signal with an amplitude of approximately 1.5 V rms.

(3) Voltmeter, 0.5% accurate at 24 V, input impedance 1 M or higher. Suggested instrument--NLS type X2.

(4) Attenuator, input impedance 10 k or higher, 1% accurate, attenuations of 1/20 and 1/200.

(5) Cables to interconnect the Model 121 and the test instruments.

6.4 PRELIMINARY STEPS

(1) Remove the top and bottom covers.

(2) Check the three fuses.

(3) Turn the power on.

6.5 POWER SUPPLY CHECKS

(1) Monitor pin 17 of the Power Supply Board with the voltmeter. The indicated voltage should be -33 V (±2 V). If the voltage is missing or low, check the AC and unregulated DC components. Assuming the voltage is correct, go on to check for -24 V (±0.3 V) at pins 1, 6, and 8. If the voltage is missing or out of tolerance, the problem is most likely in the -24 V regulator circuit (Power Supply Board). However, the possibility of a low impedance path to ground in the circuitry supplied by the -24 V regulator should not be overlooked.

(2) Monitor pin 13 of the Power Supply Board. The indicated voltage should be +33 V (±2 V). If the voltage is missing or low, check the AC and unregulated DC components. Assuming the voltage is correct, check for +24 V at pins 2, 7, and 9. If the voltage is missing or out of tolerance, the problem is probably in the +24 V regulator. Again, do not overlook the possibility of a low impedance path in the circuitry supplied by the regulator. If both the -24 V and +24 V levels are within tolerance, proceed to the following paragraph.

6.6 EXTERNAL f/2 CIRCUIT CHECK

(1) Set the Mode Switch to "EXT. f/2" and connect the oscillator output to the "REF. IN/OUT" Jack. The oscillator output signal should be a 1.5 V sine wave at 1 kHz.

(2) Monitor pin 19 of the Power Supply Board with the oscilloscope. The observed signal should be as shown in Figure V-2, page V-3. If the signal is other than as indicated, the f/2 circuit, which is located on the Power Supply Board, is defective. If the signal is normal, disconnect the oscillator and proceed to the following paragraph.

6.7 REFERENCE CHECKS

(1) Set the front panel controls as follows.

Main Tuning Dial -----------------------	4.0
Frequency Multiplier Switch -----------	$X10^2$
Mode Switch ---------------------------	CAL. 10 mV
Meter/Monitor Switch ------------------	REF.
Time Constant -------------------------	100 mS and 6 dB
Zero Suppress Switch ------------------	center position
Zero Suppress Dial --------------------	fully counter-clockwise
Phase Quadrant Selector ---------------	0
Phase Control -------------------------	0

(2) Connect the oscilloscope to the front-panel Monitor Jack.

(3) Note the panel meter indication and the scope display. The meter should indicate between 45% and 55% of full scale to the right and the monitored waveform should be a 2.8 V peak-to-peak sine wave at the tuned frequency. This signal should be referenced to approximately +10 V. If both the scope and meter indications are normal, proceed to step 4.

(a) If the waveform at the Monitor Jack is normal but the meter indication is abnormal, the Mixer Board is probably at fault.

(b) If both the meter indication and the observed waveform are abnormal, the malfunctioning circuit is probably located on the Reference Tuned Amplifier Board.

(4) Monitor the signal at each of the four lugs of the Phase Quadrant Switch which have a coaxial cable connected to them. The observed signal at each of these lugs should be a 2.8 V peak-to-peak sine wave at the tuned frequency. Each should be referenced to approximately +11 V. If the observed signals are as indicated, proceed to the Mixer and DC Amplifier Checks, which follow. If one or more of the signals is abnormal, the problem can probably be isolated to the associated phase-splitter circuits on the Reference Tuned Amplifier Board.

6.8 MIXER AND DC AMPLIFIER CHECKS

(1) Set the Meter/Monitor Switch to "OUT" and the Sensitivity Switch to "10 mV".

(2) Observe the panel meter. It should indicate "0". If it does not, turn off the power and remove the Signal Tuned Amplifier Board. Then turn the power back on and again note the panel meter indication after allowing a minute or two for the circuits to stabilize. If the meter now indicates "0" where formerly it did not, there is probably a malfunction in either the Preamplifier Board or in the Signal Tuned Amplifier Board. If the indication is still non-zero, the Mixer Board is defective. Assuming the meter indicated "0" without

having to remove the Signal Tuned Amplifier Board, preceed to Step 2.

(3) Set the Zero Suppress Switch to "+". Then begin slowly turning the Zero Suppress Dial clockwise. The meter indication should track the dial setting and should reach +100% full scale deflection when the dial setting is "1.0" (10% of its total range).

(4) Set the Zero Suppress Switch to "-". The meter indication should immediately go to -100% of full scale. Rotate the dial counter-clockwise from the "1.0" setting. The meter indication should track the dial setting. When the dial reaches the fully counter-clockwise position, the meter should indicate "0". If abnormal indications were noted in steps 3 or 4, the Mixer Board is defective. If all normal indications are obtained, set the Zero Suppress Switch to the center position and go on to the Preamplifier and Signal Board checks, which follow.

6.9 PREAMPLIFIER AND SIGNAL BOARD CHECKS

(1) Connect a cable from the "REF. IN/OUT" Jack to the "SIG. IN" Jack. Then set the Meter/Monitor Switch to "SIG." and the Q Control to "10". If the Signal Board was removed in carrying out the steps of paragraph 6.7, return it to its socket.

(2) Observe the panel meter and adjust the Frequency Trim Control for maximum meter deflection. It should indicate +100% of full scale. If it does not, vary the "ADJ." Control as required to obtain the desired full-scale deflection. If one can not obtain the proper meter indication, the problem can be in either the Preamplifier Board or in the Signal Board. In any case, proceed to step 3.

(3) Set the Meter/Monitor Switch to "OUT". Then adjust the Frequency Trim Control and the Phase Control as required to obtain maximum meter indication. The final indication should be +100%. Whether or not this step can be accomplished, proceed to step 4.

(4) Compare the results of steps 2 and 3. If the proper results were obtained in both cases, the Signal Board is functioning normally and the check should proceed to step 5, which checks the Preamplifier. If abnormal results were obtained both times, either the Preamplifier Board or the Signal Board could be defective and one should proceed to step 6. Finally, if step 2 gave an improper indication but step 3 gave a proper indication, the Signal Board is defective.

(5) Set the Sensitivity Switch to "20 mV". The meter indication should decrease from 100% to 50% of full scale. Then set the Sensitivity Switch to "50 mV". The meter indication should decrease from 50% to 20% of full scale. If the specified indications are obtained, Preamplifier A1 is functioning normally.

Connect a 20:1 attenuator between the "REF. IN/OUT" Jack and the

"SIG. IN" Jack. Then set the Sensitivity Switch to "500 μV". The meter deflection should be full scale to the right. If it is not, Preamplifier A2 is probably defective. If the proper indication is obtained, both A1 and A2 are functioning properly.

Connect a 200:1 attenuator between the "REF. IN/OUT" Jack and the "SIG. IN" Jack. Then set the Sensitivity Switch to "50 μV". Again the meter indication should be +100% of full scale. If it is not, Preamplifier A3 is defective. NOTE: In making this measurement, check for ground-loop current as directed in the note on page V-13. If the proper indication is obtained, and proper indications have been obtained in all preceding steps, the malfunction is one which can not be isolated with this procedure. Should this be the case, contact PAR or one of PAR's authorized representatives for aid. NOTE: steps 6 and 7, which follow, apply only if abnormal results were obtained in steps 2 and 3.

(6) Remove the attenuator, connect the "REF. IN/OUT" Jack directly to the "SIG. IN" Jack, and set the Sensitivity Switch to "10 mV". Then monitor pin 20 of the Preamplifier Board with the oscilloscope. The observed signal should be a square wave with a peak-to-peak amplitude of approximately 2 mV. If this signal is missing, the defective component is probably the source follower located on the Sensitivity Switch. If the signal is normal, proceed to step 7.

(7) Remove the Signal Tuned Amplifier and monitor the signal at pin 6 of the Preamplifier Board. The observed signal should be a square wave with a peak-to-peak amplitude in the range of 40 mV to 80 mV. This signal should be referenced to -14.5 V. If normal indications are obtained, the Signal Board is defective. If the observed signal is not as indicated, the problem is in the Preamplifier Board.

SECTION VII
WARRANTY

Princeton Applied Research Corporation warrants each instrument of its own manufacture to be free from defects in material and workmanship. Obligations under this Warranty are limited to replacing, repairing or giving credit for the purchase price, at our option, of any instrument returned prepaid to our factory for that purpose within ONE year of delivery to original purchaser. Instruments returned to the factory are accepted only when prior authorization has been given by an authorized representative of Princeton Applied Research Corporation.

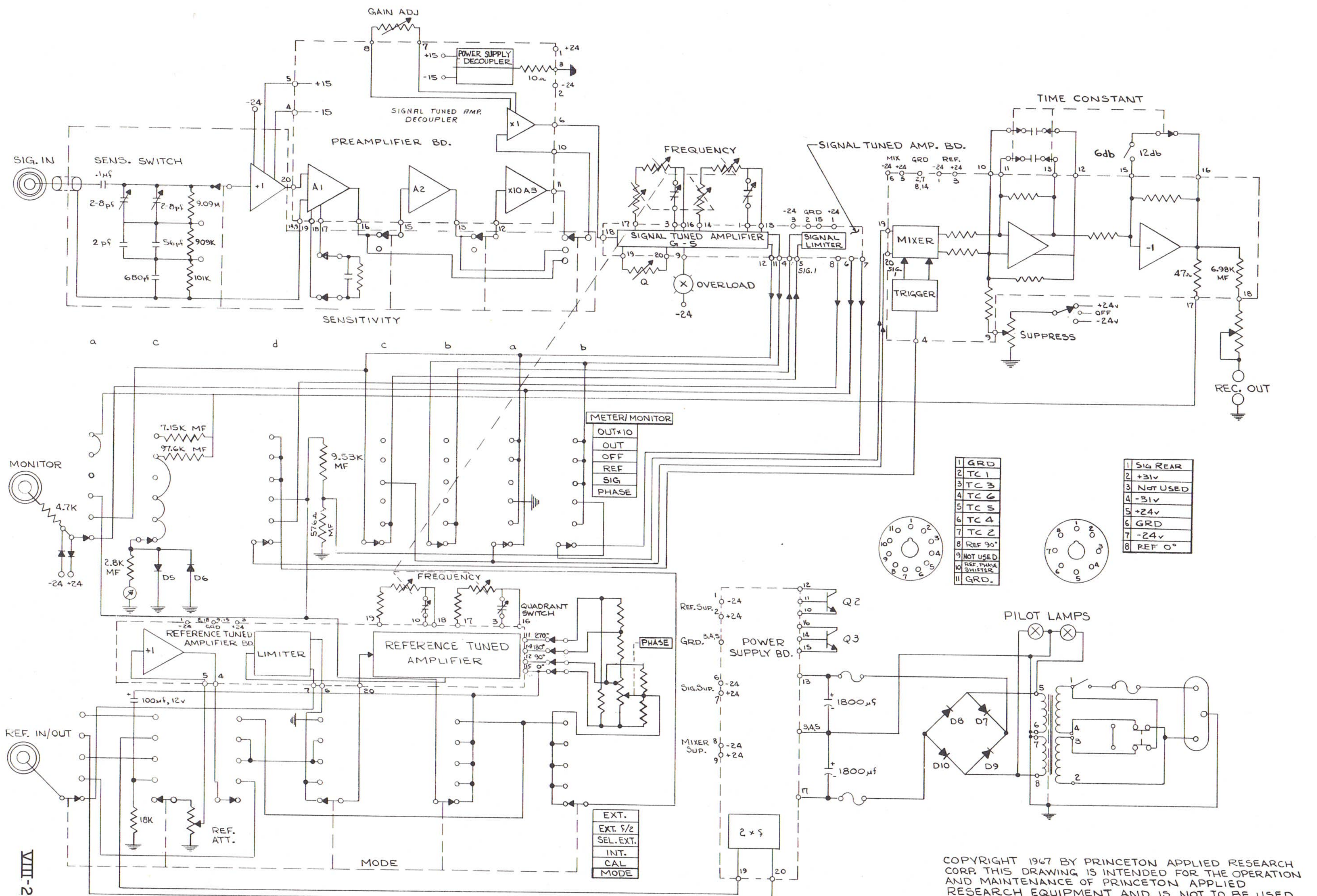
This Warranty shall not apply to any instrument, which our inspection shall disclose to our satisfaction, to have become defective or unworkable due to abuse, mishandling, misuse, accident, alteration, negligence, improper installation, or other causes beyond our control.

Princeton Applied Research Corporation reserves the right to make changes in design at any time without incurring any obligation to install same on units previously purchased.

This Warranty is in lieu of, and excludes all other warranties or representations, expressed, implied or statutory, and all other obligations or liabilities of Princeton Applied Research Corporation including special or consequential damages, and no other source is authorized to assume for Princeton Applied Research Corporation any other liability.

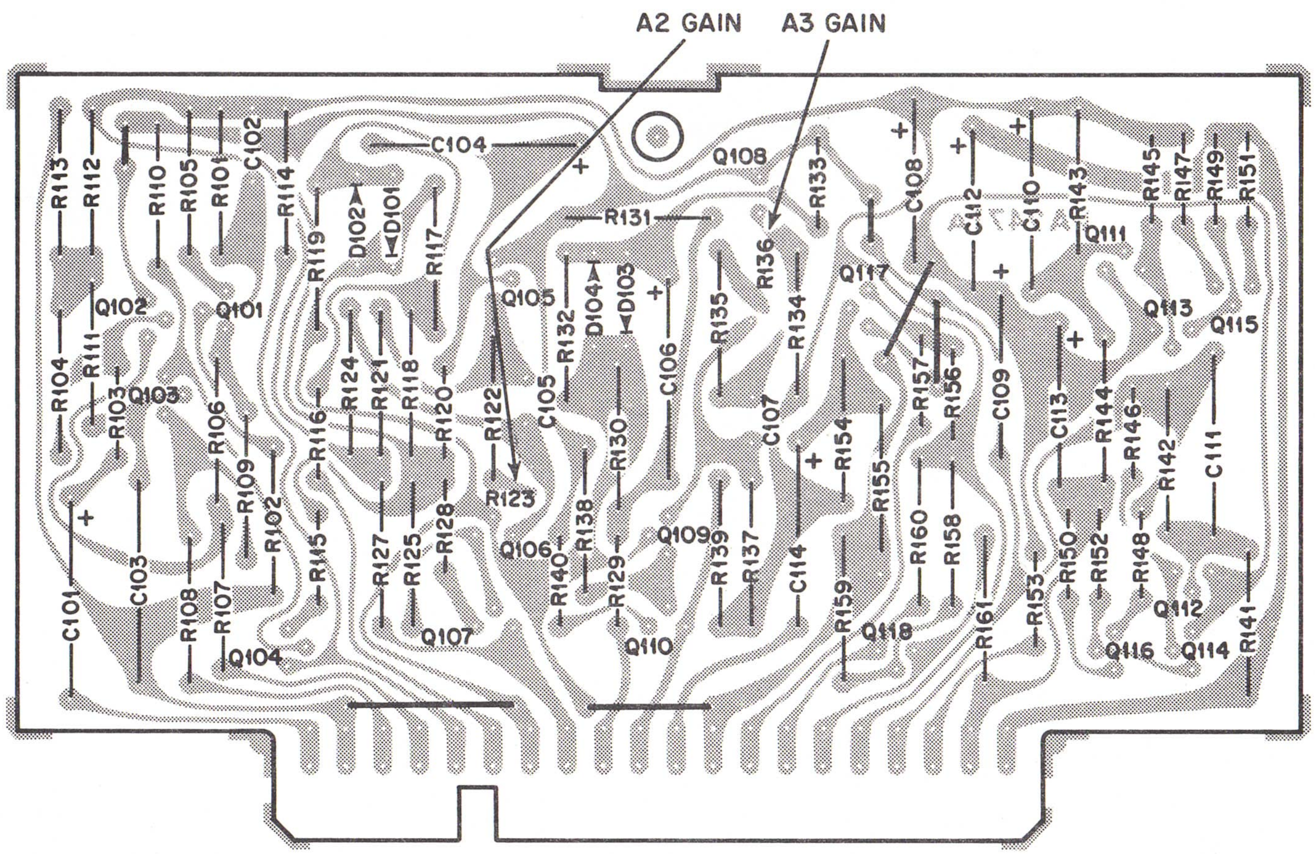
SECTION VIII
SCHEMATICS

The voltages and waveforms indicated on the schematics were measured under "Gain Calibration" conditions. To establish these conditions, carry out steps 1 through 3-c of the Gain Calibration Procedure as given on page III-4. EXCEPTIONS: (1) The waveforms indicated for the Frequency Doubler Circuit (page VIII-7) were obtained by applying a 5 V peak-to-peak sine wave (400 Hz) to the Reference "IN/OUT" Jack with the Mode Switch set to "EXT. f/2". (2) The waveforms indicated for the Signal Limiter Circuit (page VIII-4) were measured under AC Voltmeter calibration conditions as given on pages III-24 and III-25.

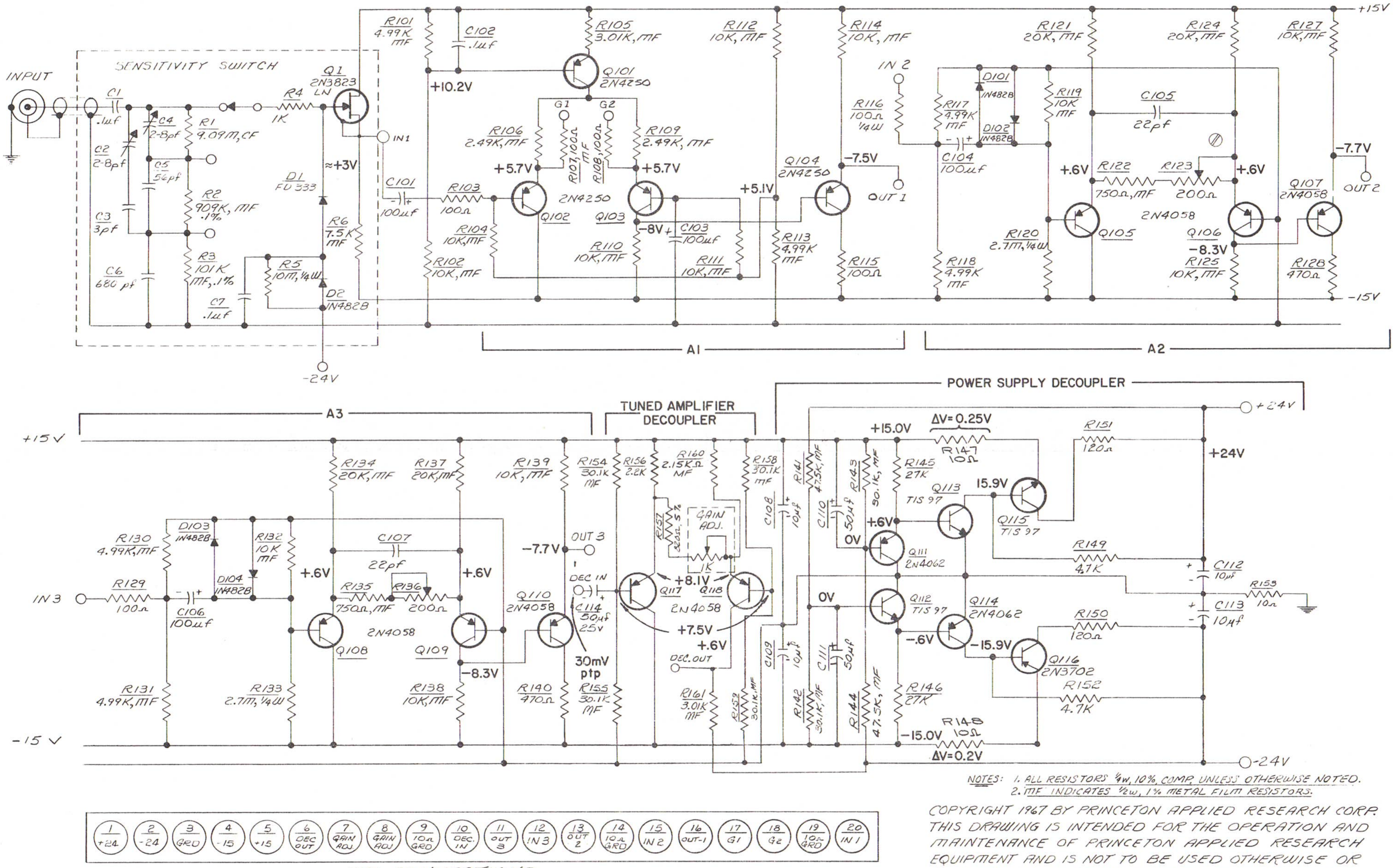


BLOCK DIAGRAM - 121

2454 C SD E



PREAMPLIFIER BOARD



PIN CONNECTIONS

NOTES: 1. ALL RESISTORS ¼W, 10% COMP. UNLESS OTHERWISE NOTED.
2. MF INDICATES ½W, 1% METAL FILM RESISTORS.

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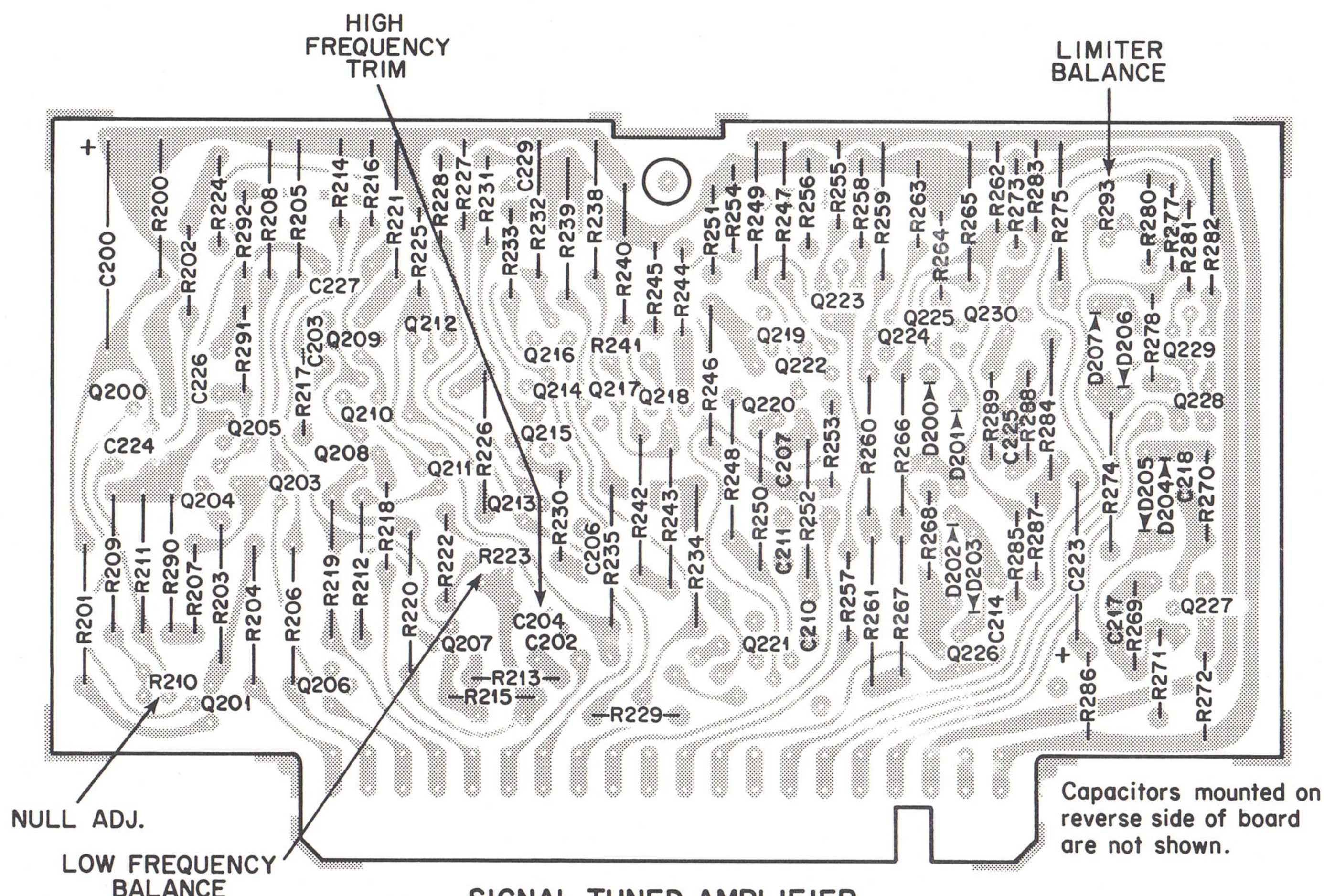
NOTES:
1. 2N3391A OR 2N3711 TRANSISTORS MAY BE SUBSTITUTED FOR TIS 97.

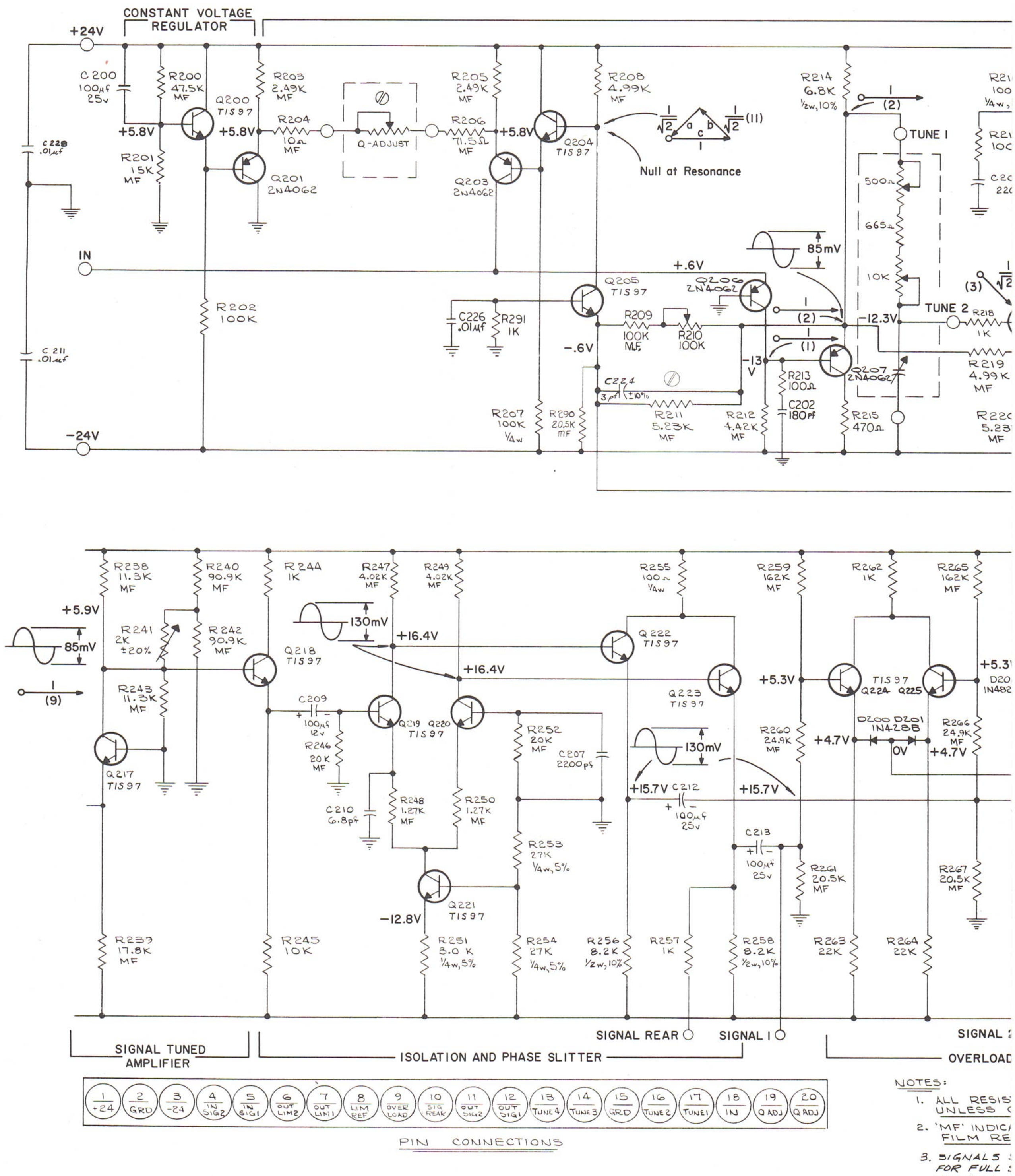
LAST 'R' Nº USED = R161
LAST 'C' Nº USED = C114
LAST 'D' Nº USED = D104

PRE-AMPLIFIER BD. SCHEMATIC MODEL-121 CIRCUIT BD. #2471

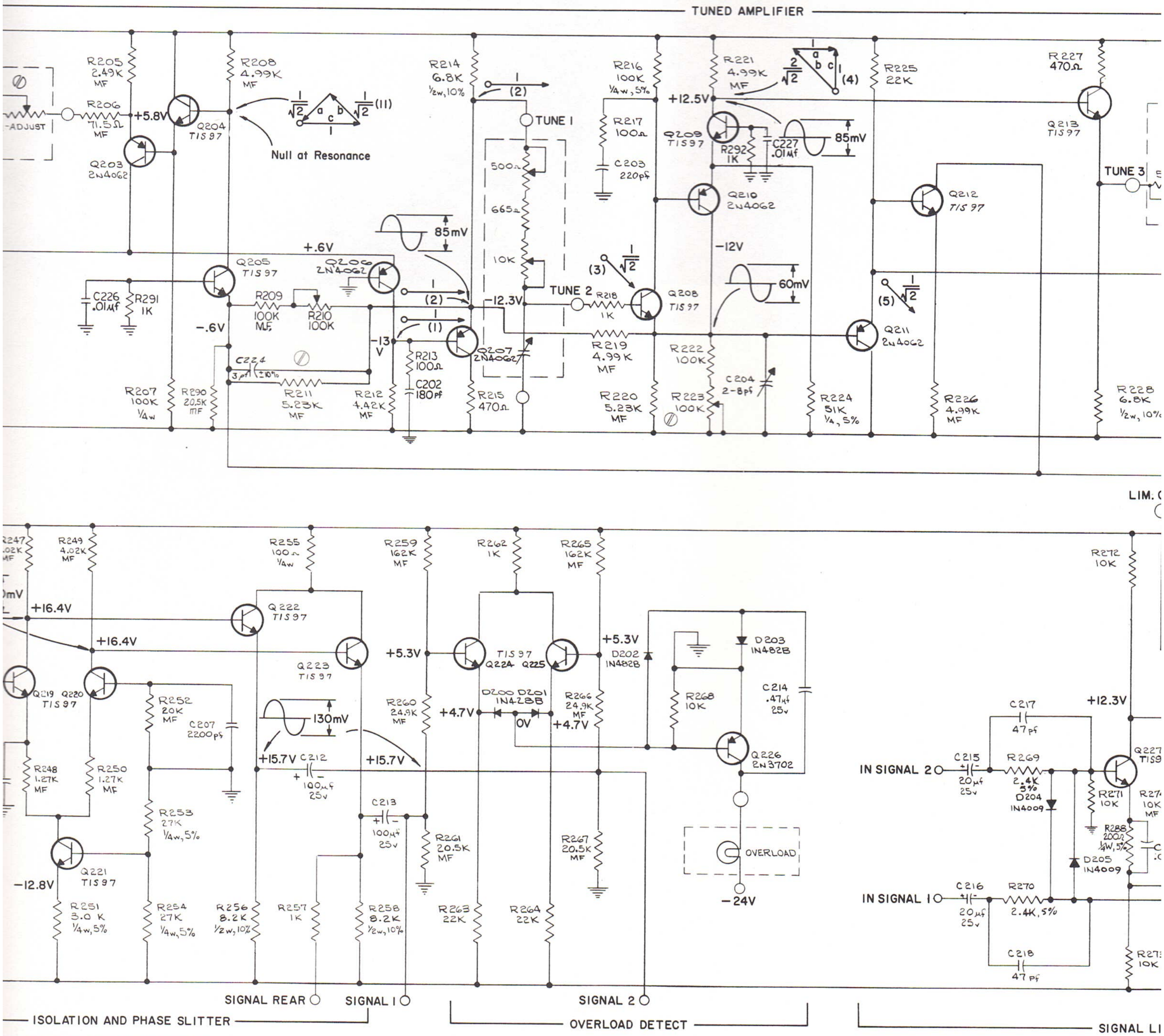
2459 C SD C



SIGNAL TUNED AMPLIFIER



SIGNAL TUNED AMP. SCHEMATIC MODEL 121 CIRC



9	10	11	12	13	14	15	16	17	18	19	20
OVER LOAD	SIG REAR	OUT SIG 2	OUT SIG 1	TUNE 4	TUNE 3	GRD	TUNE 2	TUNE 1	IN	Q ADJ	Q ADJ

PIN CONNECTIONS

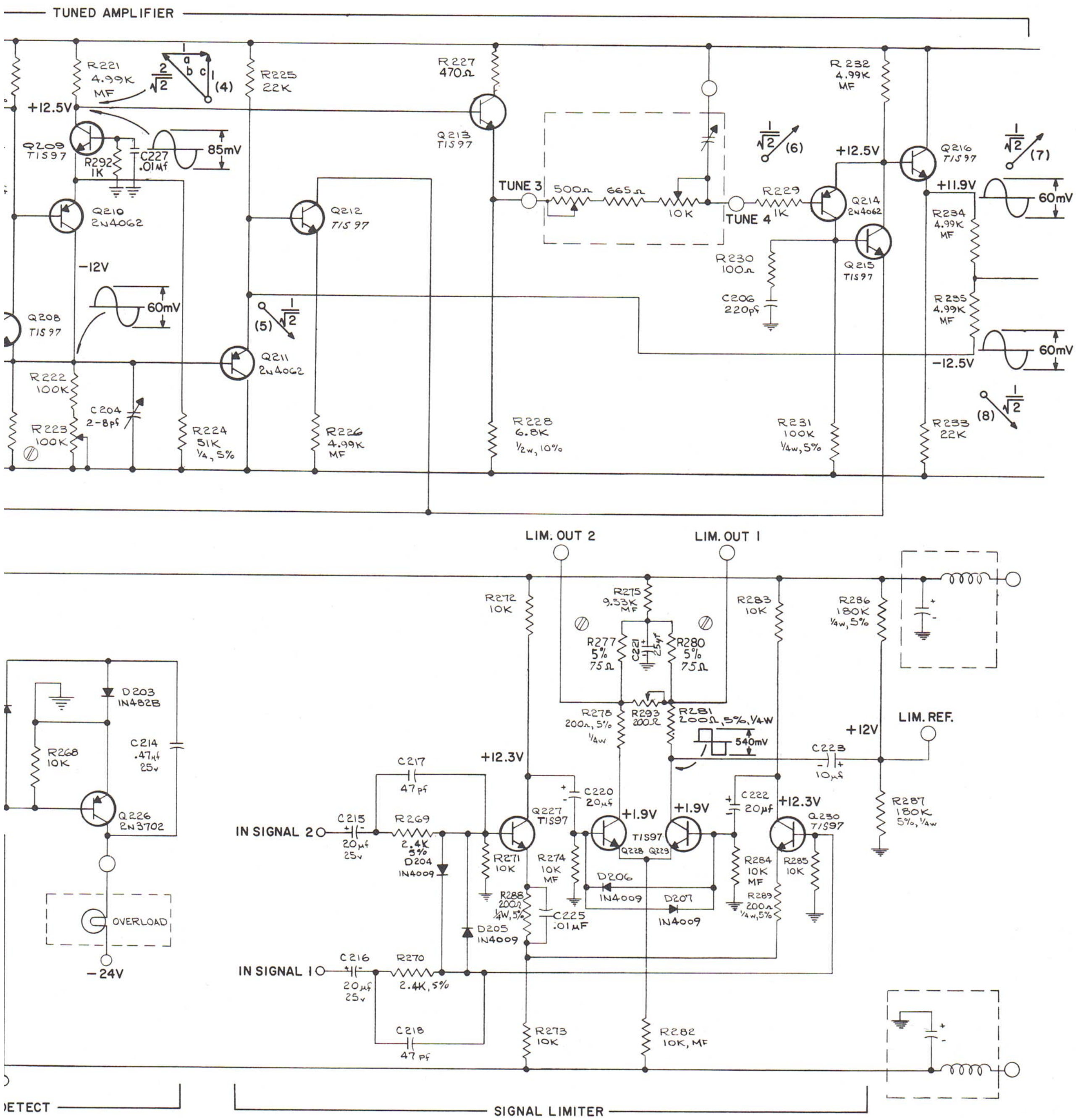
NOTES:

1. ALL RESISTORS 1/4 WATT, 10% COMP. UNLESS OTHERWISE NOTED.
2. 'MF' INDICATES 1/2 WATT, 1% METAL FILM RESISTORS.
3. SIGNALS SHOWN: INSTRUMENT SET FOR FULL SCALE USING THE CALIBRATION VOLTAGE.

LAST 'R' No USED = R293
LAST 'C' No USED = C229

4. 2N3391A OR 2N3711 TRANSISTORS MAY BE SUBSTITUTED FOR TIS 97.

ATIC MODEL 121 CIRCUIT BD # 2467



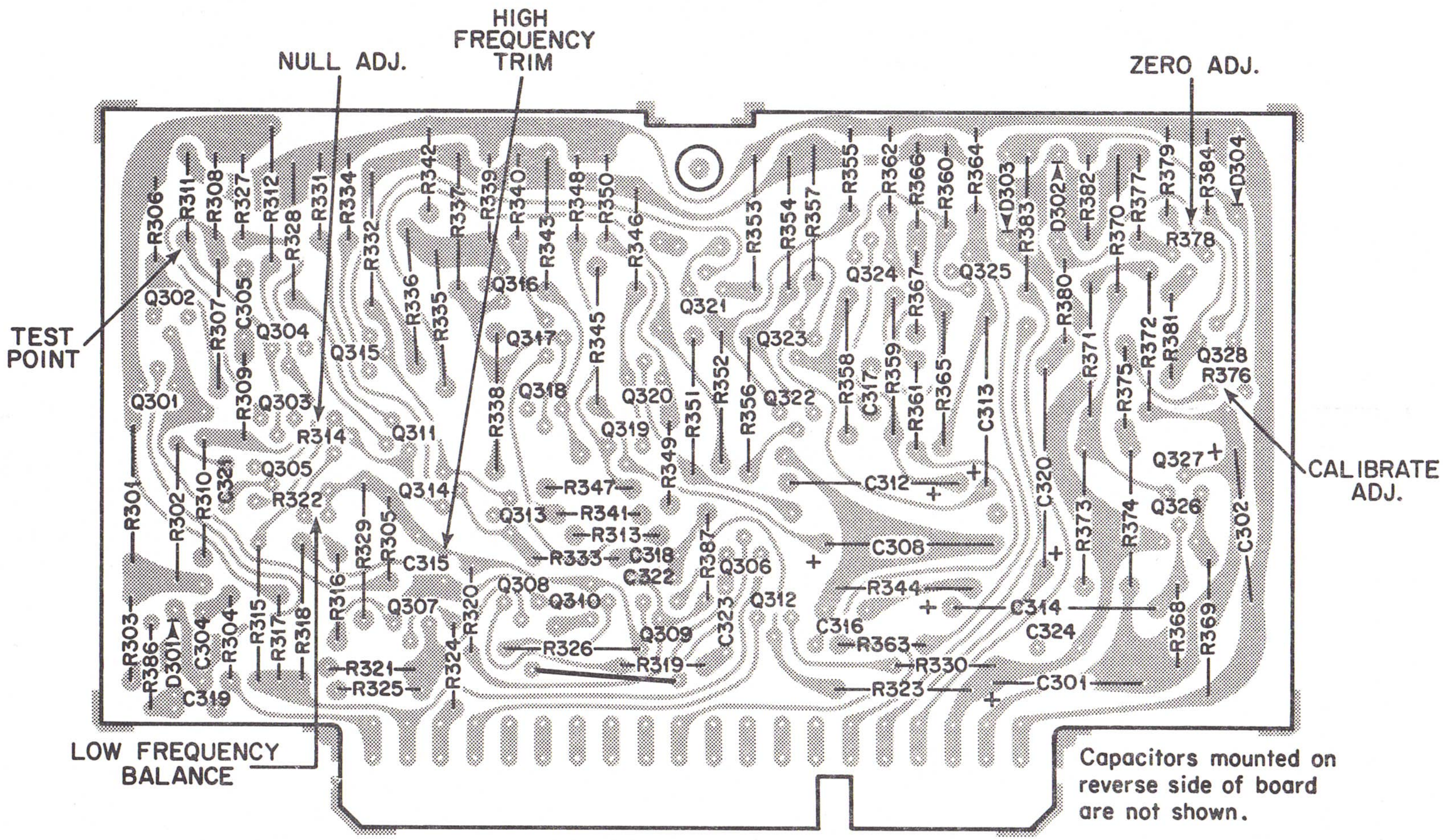
LAST 'R' No USED = R293
LAST 'C' No USED = C229

4. 2N3391A OR 2N3711 TRANSISTORS MAY BE SUBSTITUTED FOR TIS 97.

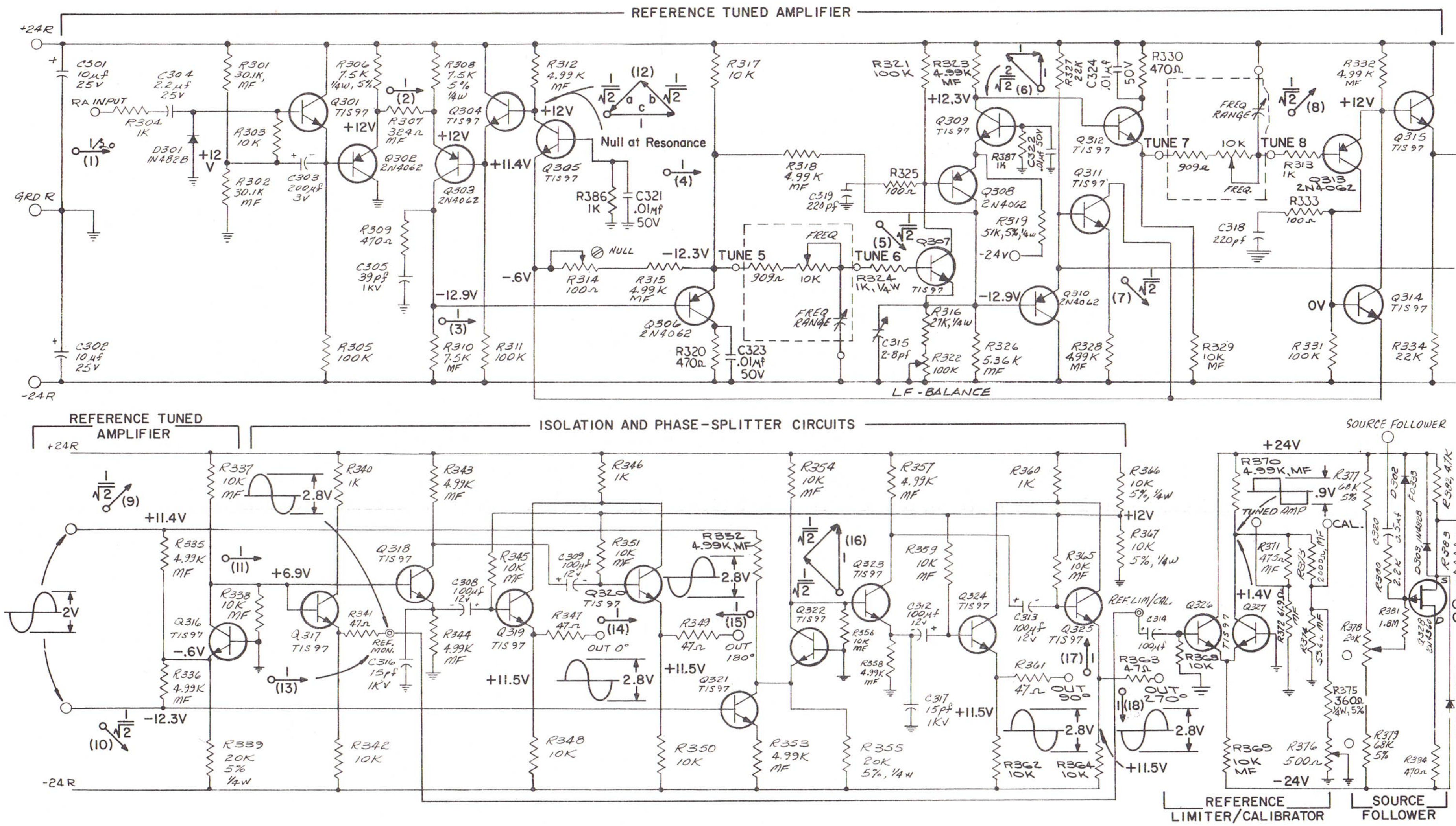
ORS 1/4 WATT, 10% COMP.
HERWISE NOTED.
ES 1/2 WATT, 1% METAL
STORS.
OWN: INSTRUMENT SET
ALE USING THE CALIBRATION

IIT BD # 2467

2455 D SD K



REFERENCE TUNED AMPLIFIER BOARD



LAST 'R' Nº USED: R387
LAST 'C' Nº USED: C324

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
-24	GRD	+24	SOURCE FOLLOUT	SOURCE FOLL IN	TUNED AMP REF LIM	CALIB.	GRD.	GRD	GRD	270°	90°	MON	180°	0°	T8	T7	T6	T5	REF IN

PIN CONNECTIONS

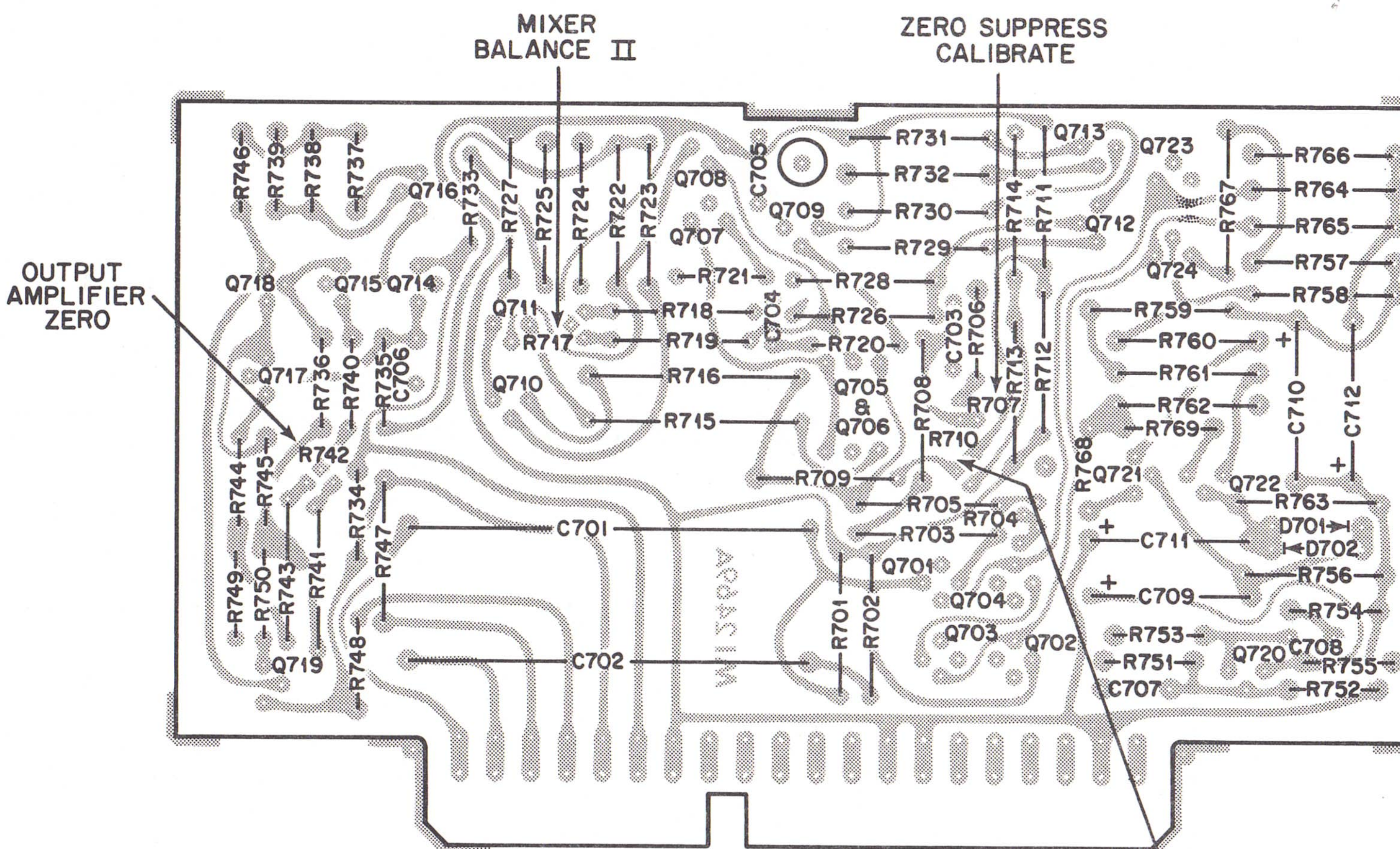
NOTES:
1. ALL RESISTORS ¼W, 10% COMP. UNLESS OTHERWISE NOTED.
2. 'M.F.' INDICATES ½W, 1%, METAL FILM RESISTORS.
3. SCOPE TRIGGER ON + FROM REF IN/OUT MODE ON IN TERNAL.
4. 2N3391A OR 2N3711 TRANSISTORS MAY BE SUBSTITUTED FOR TIS 97.

REFERENCE TUNED AMP. SCHEMATIC

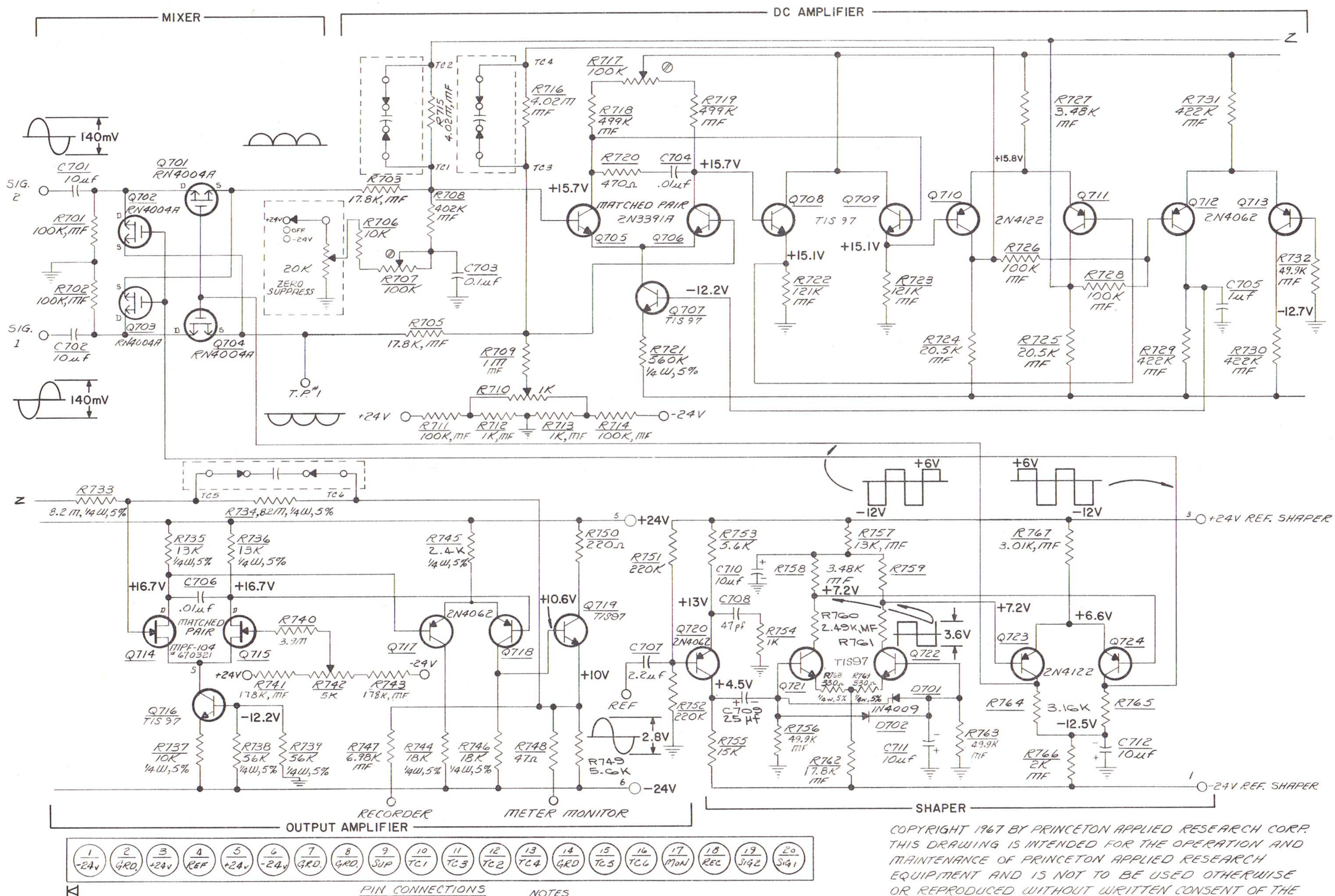
MODEL-121

BD #2468

2456 | C | SD | D


MIXER
BALANCE II
ZERO SUPPRESS
CALIBRATE
OUTPUT
AMPLIFIER
ZERO
MIXER BALANCE I

MIXER BOARD



NOTES

1- ALL RESISTORS 1/4 WATT, 10% COMPOSITION UNLESS OTHERWISE NOTED.

2- 'M.F.' INDICATES 1/2W, 1% METAL FILM RESISTORS.

3. SIGNALS SHOWN: INSTRUMENT IS SET FOR FULL SCALE USING THE CALIBRATION VOLTAGE.

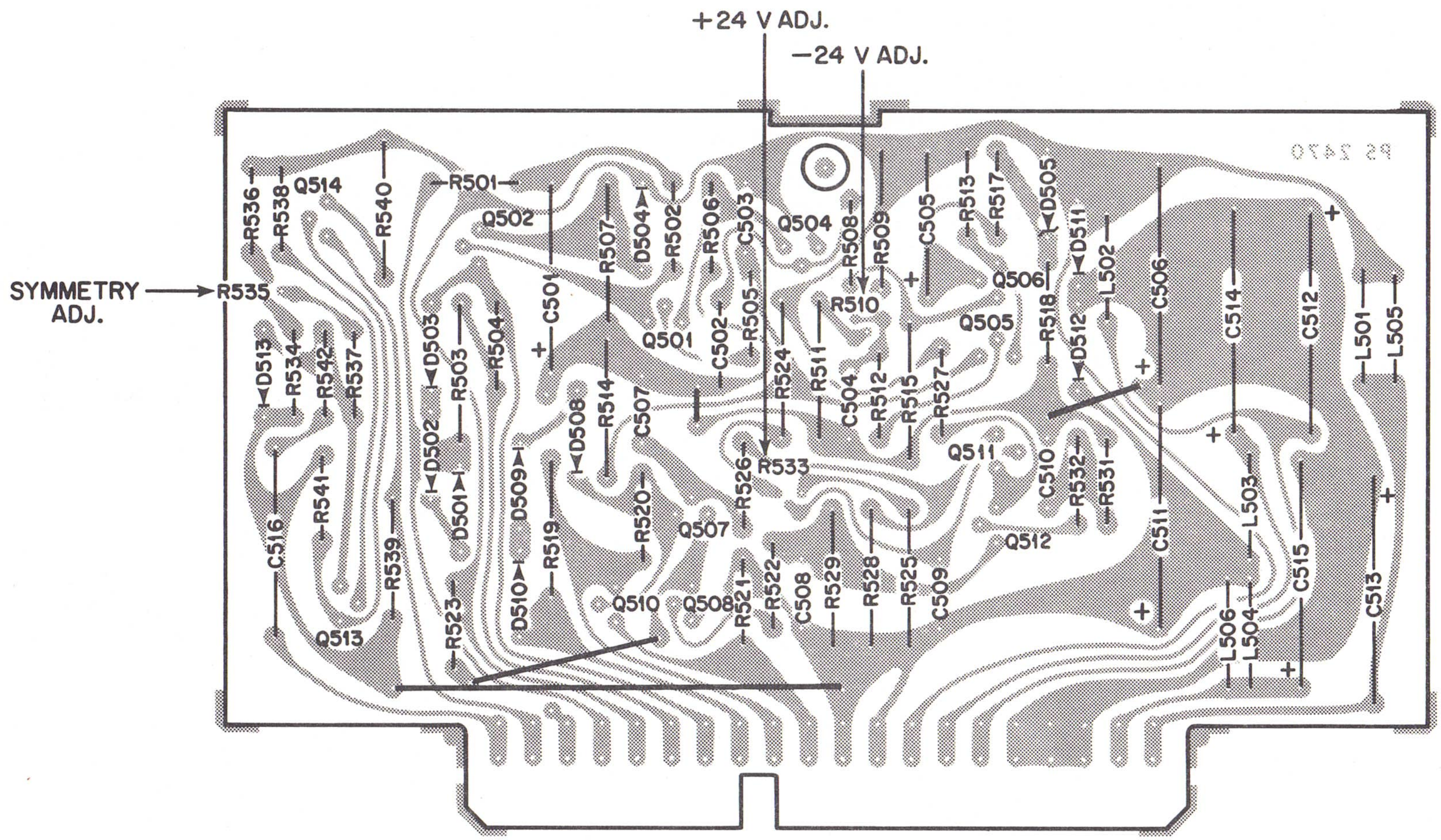
4. 2N3391A OR 2N3711 TRANSISTORS MAY BE SUBSTITUTED FOR TIS97.

VIII-6

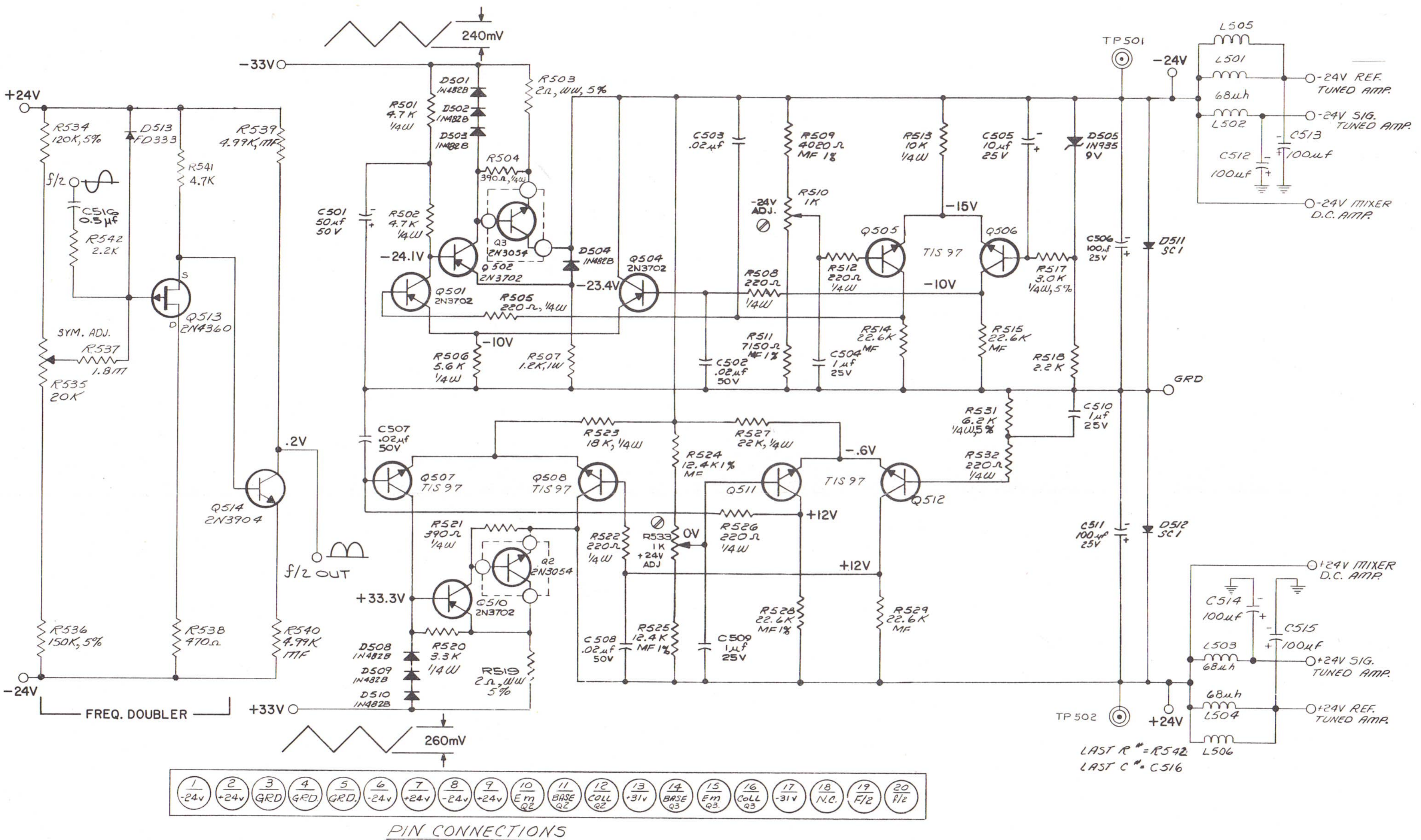
MIXER BD. SCHEMATIC MODEL 121

CIRCUIT BD. #2469

2457 C SD E



POWER SUPPLY BOARD

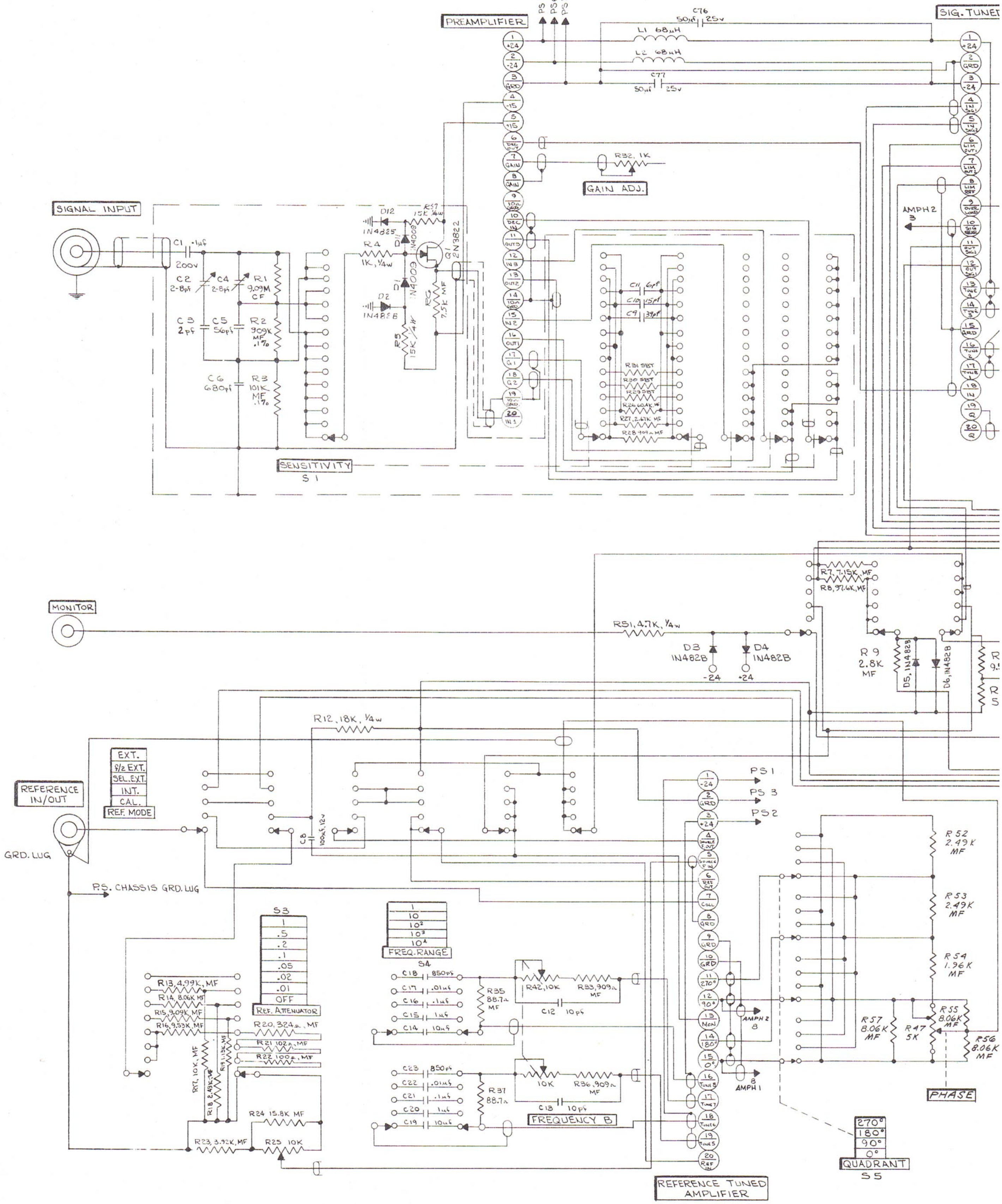


POWER SUPPLY SCHEMATIC MODEL-121

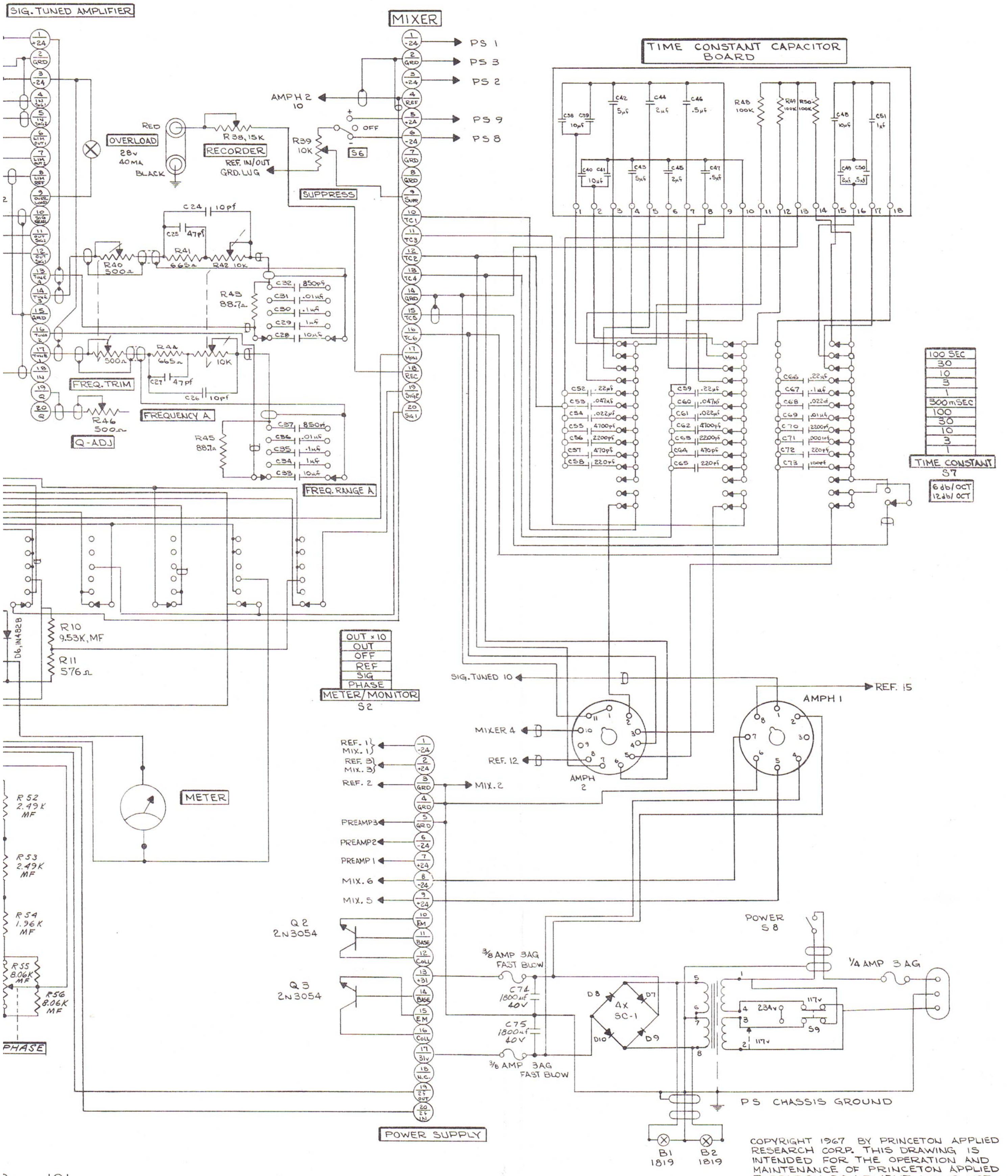
CIRCUIT BOARD # PS2470

NOTES:

1- ALL RESISTORS ½ WATT COMP. UNLESS OTHERWISE NOTED.
2- 'M.F.' INDICATES ½ WATT, 1% METAL FILM RESISTORS.
3- 2N3391A OR 2N3711 TRANSISTORS MAY BE SUBSTITUTED FOR TIS 97.



CHASSIS WIRING SCHEMATIC — 121


SIG. TUNED AMPLIFIER
MIXER
PS 1
PS 3
PS 2
PS 9
PS 8
AMPH 2 10
OFF
S6
RED
BLACK
OVERLOAD
28v 40MA
R38, 15K
RECORDER
REF. IN/OUT GRD. LUG
R39 10K
SUPPRESS
TIME CONSTANT CAPACITOR BOARD
R48 100K
C24 10pf
C25 47pf
R41 665Ω
R42 10K
R40 500Ω
R43 88.7Ω
C32 850pf
C31 .01μf
C30 .1μf
C29 1μf
C28 10μf
R44 665Ω
500Ω
10K
FREQ. TRIM
C27 47pf
C26 10pf
R46 500Ω
Q-ADJ
FREQUENCY A
R45 88.7Ω
C37 850pf
C36 .01μf
C35 .1μf
C34 1μf
C33 10μf
FREQ. RANGE A
C52 .22μf
C53 .047μf
C54 .022μf
C55 4700pf
C56 2200pf
C57 470pf
C58 220pf
C59 .22μf
C60 .047μf
C61 .022μf
C62 4700pf
C63 2200pf
C64 470pf
C65 220pf
C66 .22μf
C67 .1μf
C68 .022μf
C69 .01μf
C70 2200pf
C71 .001μf
C72 220pf
C73 100pf
100 SEC
30
10
3
1
300 mSEC
100
30
10
3
1
TIME CONSTANT
S7
6 db/OCT
12 db/OCT
R10 9.53K, MF
R11 576Ω
D6, IN482B
OUT × 10
OUT
OFF
REF
SIG
PHASE
METER/MONITOR
S2
SIG. TUNED 10
REF. 15
AMPH 1
MIXER 4
REF. 12
AMPH 2
METER
R52 2.49K MF
R53 2.49K MF
R54 1.96K MF
R55 8.06K MF
R56 8.06K MF
PHASE
REF. 1 MIX. 1
REF. 3 MIX. 3
REF. 2
MIX. 2
PREAMP 3
PREAMP 2
PREAMP 1
MIX. 6
MIX. 5
Q2 2N3054
Q3 2N3054
3/8 AMP 3AG FAST BLOW
C74 1800μf 40V
C75 1800μf 40V
3/8 AMP 3AG FAST BLOW
D8
D7
4X SC-1
D10
D9
POWER S8
1/4 AMP 3AG
234v
117v
S9
PS CHASSIS GROUND
POWER SUPPLY
B1 1819
B2 1819

APPENDIX
BATTERY OPERATION

INTRODUCTION

Battery operation of the Model 121 Lock-In Amplifier/Phase Detector may be necessary where no ac power is available or as a last resort where power line interference is a problem. This may be achieved simply by connecting batteries in parallel with the ±31 V unregulated lines.

EQUIPMENT NEEDED

(1) Two 31 V (±3 V) batteries, each capable of supplying 300 mA at this voltage.

(2) One red binding post connector, one green binding post connector, and one grounding type binding post connector.

(3) Sufficient #18 insulated wire to connect the terminals and the batteries according to the following procedure.

PROCEDURE

(1) Remove the top cover.

(2) The transformer, rectifiers, and filter capacitors for the unregulated ±31 V power supply are located on the chassis at the far right-rear of the instrument. Two fuses in this location are connected between the capacitors and the regulator circuits. The connections are to be made to the capacitor side (end of fuse closest to rear panel) of the fuses. Energize the instrument, and check the dc voltages at the fuses. Note which fuse is for minus 31 V and which is for plus 31 V.

(3) Unplug the line cord.

(4) Mount the three binding post connectors on the rear panel conveniently near the fuses.

(5) Connect the red binding post to the rear-panel side of the fuse that carries the positive 31 V line.

(6) Connect the green binding post to the rear-panel side of the fuse that carries the minus 31 V line.

(7) Replace the top cover.

(8) Connect the positive side of one battery to the red binding post, and connect the negative side of the other battery to the green binding post. Then connect the remaining two battery terminals together, and connect this point to the grounding binding post.

NOTE: IT IS VERY IMPORTANT THAT BATTERY (polarity) REVERSAL NEVER OCCURS.

The instrument should now be energized with the batteries. Battery operation differs from power line operation only in that the power lamp does not light and the power switch does not operate. To turn the instrument off when using battery power, disconnect the battery leads from the binding posts. The user may install a battery power switch if he so desires (double pole). Leaving the batteries connected while operating with line power will not cause damage (as long as the batteries are at the required voltage), but this is not recommended.

NOTE: NEVER SHORT CIRCUIT THE BATTERY TERMINALS WHILE OPERATING THE INSTRUMENT WITH LINE POWER: this may damage the rectifiers or power transformer, or both. Installation of fuses in the (internal) battery line would help prevent damage should such an accident occur. Use 3/8 ampere 3AG fast-acting type fuses.

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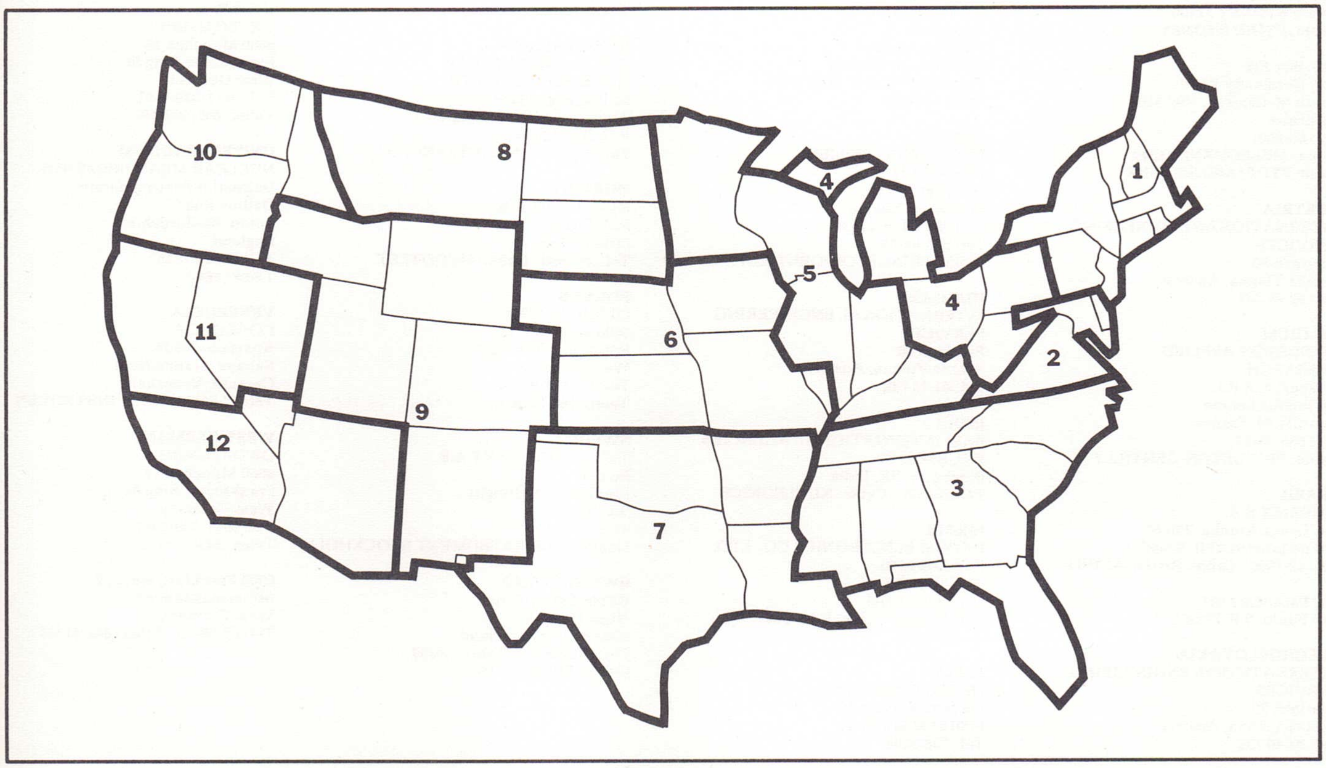

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